

IoT Product Design and Rapid Prototyping

Part B

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January 2023



Previous Capstones



Previous Capstone Playlist

<https://www.youtube.com/watch?v=s4Ts1pITeVw&list=PL0t2Pk5ETDgxfVptdyr6xbL6MW1-5CJey>

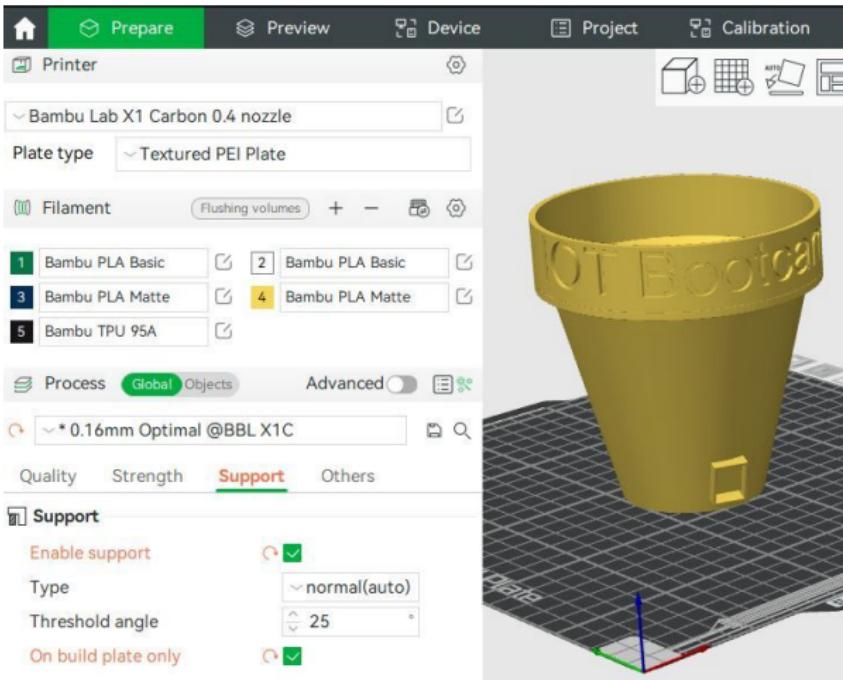


Recommendations

- Students and employers often would like references/recommendations from the instructors.
- Get permission from instructor or Deep Dive staff member before listing as a reference.
- Our recommendations are based on:
 - Ability to plan work and complete assignments on time.
 - Showing a willingness to learn and try new things.
 - Quality of documentation and use of lab notebooks
 - Willingness to help others.
 - Demonstration of learning throughout the course.



Printing IoT Flowerpot



It is important to enable support as On Build plate only .



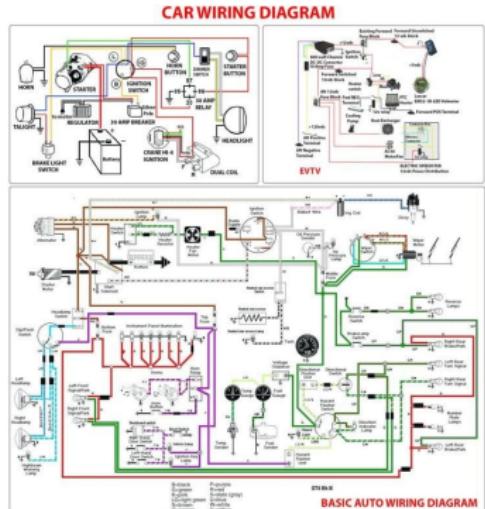
Clear Out Credentials

Going forward we will need to connect to the Internet and the Particle Cloud:

- Run L09_00_HelloReset
 - Clear out all credentials (to remove IoTClassroom)
 - Reconnect to DDCIOT
- Add your home credentials, either by:
 - Add your home credentials to L09_00_HelloReset, or
 - When you get home, use <https://docs.particle.io/tools/developer-tools/configure-wi-fi/> to reconnect to your home wifi
- Code also will show you your stored credentials, your IP and MAC address, and the Access Point info.



A Word About Schematics



Some sensors went out on my car so I did some looking things up and ordered the parts and then downloaded the repair manual. There are pages and pages of electrical systems diagrams and thanks to you and the class and spending 10+ weeks constantly making wiring diagrams they're not terrifying and actually make sense. IoT class meets auto repair. Thank you.

– Artist from Cohort 11



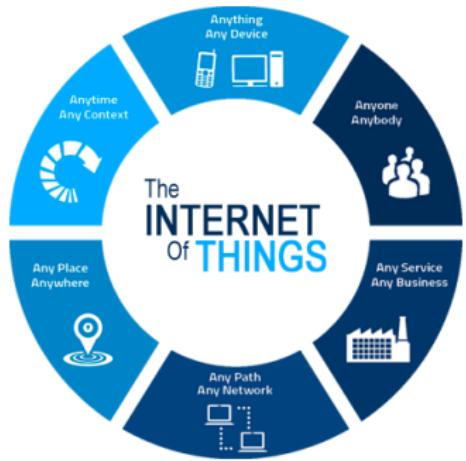
The Use of Functions: L09_00_Function

- Benefits of using functions
 - ① Enables reusability and reduces redundancy
 - ② Makes code modular
 - ③ Provides abstraction functionality
 - ④ Makes the program easier to understand and manage
 - ⑤ Breaks an extensive program into smaller and simpler pieces
 - ⑥ Reduces interference between variable names
- It is common during the first midterm for students to avoid the use of functions or to use global variables across functions.
- For the second midterm (Smart Houseplant Watering System) you will be asked to make appropriate use of functions.
- Review L09_00_Function. In your notebook:
 - ① Document the functionality of this C++ code
 - ② Note observations about how the overall code is written
 - ③ Identify any questions you have about the code

Module 9 - The Cloud



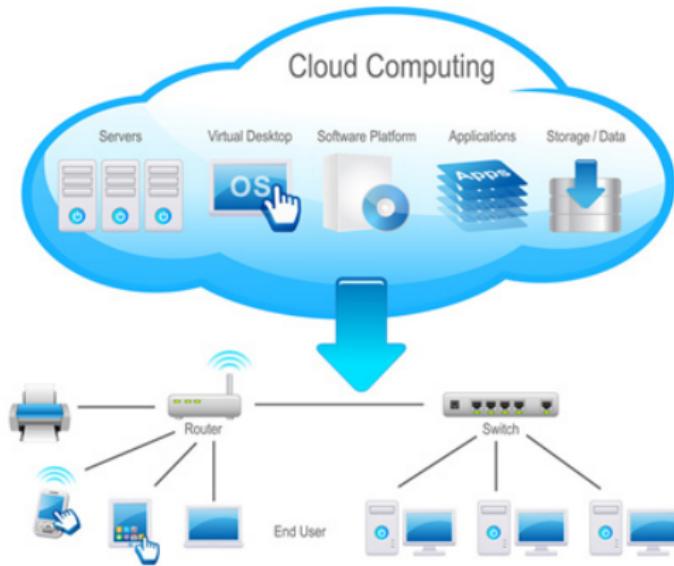
Module 9 Objectives



- Learning Objectives
 - ① Communicating to the cloud using MQTT
 - ② Javascript Object Notation (JSON)
 - ③ Webhooks
- Additional Items
 - ① 3D Modeling Lesson 4 - Tubes
 - ② Quiz 6



The Cloud



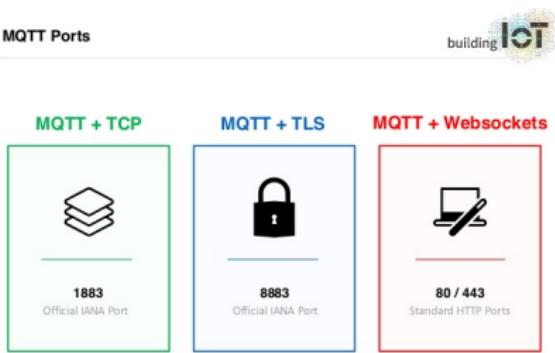


MQTT: MQ Telemetry Transport

Publish / Subscribe



MQTT Ports





Adafruit.io



Let's create an Adafruit.io account.

Get Started

FREE
forever

30 data points per minute
30 days of data storage
Triggers every 15 minutes
5 feed limit

[Sign Up Now](#)

Power Up

\$10 or \$99
per month per year

60 data points per minute
60 days of data storage
Triggers every 5 seconds
Unlimited feeds

[Learn more about IO+
Sign Up Now](#)



Creating credentials.h

The credentials.h file allows you to store private data that will not be sent to github (if you are using the .gitignore file that was cloned with your repository).

From VSCode:

- File → Open Folder
- Select from L09_Cloud: L09_01_SubscribePublish
- Setup credentials.h:
 - ① Create a new file in the /src directory called credentials.h.
 - ② Type this code into it, using your own username and key:

```
1 //***** Adafruit.io Setup *****  
2 #define AIO_SERVER      "io.adafruit.com"  
3 #define AIO_SERVERPORT   1883      // use 1883 for SSL  
4 #define AIO_USERNAME     "username" // replace with your Adafruit.io username  
5 #define AIO_KEY          "key"       // replace with your Adafruit.io key
```



MQTT Elements explained

- TheClient - object that defines the TCP (Transmission Control Protocol) connection over WiFi.
- mqtt - object that defines the MQTT connection using the WiFi object, the MQTT server/port, and user name/password.
- FeedName - a "variable" located on Adafruit.io that can be subscribed or published to. There can be many of these.
- mqttObj - object that will be used in the C++ code that will be used to publish or subscribe to an Adafruit.io feed. There needs to be one object for each feed.
- value - Variable in the C++ code that stores information to be published or to receive information from a feed that is subscribed to.

NOTE: FeedName, mqttObj, and value should be given descriptive "names" similar to the naming convention for all variables and objects in the C++ code.



MQTT Elements in VSCode

```
1 #include <Adafruit_MQTT.h>
2 #include "Adafruit_MQTT/Adafruit_MQTT_SPARK.h"
3 #include "Adafruit_MQTT/Adafruit_MQTT.h"
4
5 #include "credentials.h"
6
7 // Create the TCP Client
8 TCPClient TheClient;
9
10 // Setup the MQTT client class by passing in the WiFi client and MQTT server and login
11 // details.
12 Adafruit_MQTT_SPARK mqtt(&TheClient,AIO_SERVER,AIO_SERVERPORT,AIO_USERNAME,AIO_KEY);
13
14 // **** Feeds ****
15 // Setup Feeds to publish or subscribe
16 // Notice MQTT paths for AIO follow the form: <username>/feeds/<feedname>
17 Adafruit_MQTT_Subscribe subFeed = Adafruit_MQTT_Subscribe(&mqtt,AIO_USERNAME "/feeds/
18     feed1");
19 Adafruit_MQTT_Publish pubFeed = Adafruit_MQTT_Publish(&mqtt,AIO_USERNAME "/feeds/feed2");
20
21 // **** Declare Variables ****
22 unsigned int last, lastTime;
23 float subValue, pubValue;
24
25 // **** Declare Functions ****
26 void MQTT_connect();
27 bool MQTT_ping();
```

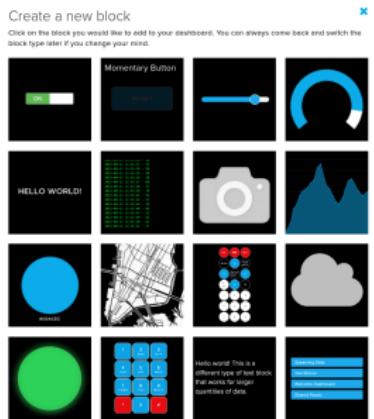


MQTT Publish and Subscribe

```
1 void setup() {
2   Serial.begin(9600);
3   waitFor(Serial.isConnected, 15000); //wait for Serial Monitor to startup
4
5   WiFi.connect(); //Connect to internet, but not Particle Cloud
6   while(WiFi.connecting()) {
7     Serial.printf(".");
8   }
9
10 mqtt.subscribe(&subFeed); // Setup MQTT subscription for subFeed feed.
11 }
12
13 void loop() {
14   // Publishing to a MQTT feed
15   if(mqtt.Update()) { //if mqtt object (Adafruit.io) is available to receive data
16     Serial.printf("Publishing %0.2f to Adafruit.io feed FeedNameB \n",value1);
17     pubfeed.publish(value1);
18   }
19   // Two new functions that will be useful:
20   // atof() - ASCII to Float: converts an ASCII string to a floating point number
21   // atoi() - ASCII to Integer: converts an ASCII string to an integer
22
23   // Receive data from a subscription to an MQTT feed
24   Adafruit_MQTT_Subscribe *subscription;
25   while ((subscription = mqtt.readSubscription(100))) { //wait a moment for new feed data
26     if (subscription == &subFeed) { // assign new data to appropriate variable
27       value2 = atof((char *)subFeed.lastread); //value2 = data from MQTT subscription
28       Serial.printf("Received %0.2f from Adafruit.io feed FeedNameB \n",value2);
29     }
30   }
31 }
```



Assignment: L09_01_SubscribePublish



- ➊ Modify the starter code for your Adafruit.io
- ➋ Publish
 - Publish a random number to a feed once every 6 seconds (do not use a delay).
 - Create a line chart on your dashboard to display the random number.
- ➌ Subscribe
 - Add a button to your dashboard and connect it to a feed called buttonOnOff.
 - Subscribe to the buttonOnOff and turn on the on board LED (D7) when pressed.
- ➍ Experiment with other blocks
 - Add a LED to pin D16.
 - Add a slider and new feed.
 - Control the brightness of an LED.
 - Display data with other dashboard blocks.



Local and Static Variables

```
1 const int TEMPFREQ = 10000, MOISTFREQ = 30000, MOISTPIN = A3;
2 float tempC;
3 int moist;
4 void loop() {
5     tempC = getTemp(TEMPFREQ);
6     moist = getMoisture(MOISTPIN, MOISTFREQ);
7 }
8
9 float getTemp(int timeInterval) {
10    int currentTime;
11    static int lastTime = -999999;
12    static float data;
13
14    currentTime = millis();
15    if(currentTime - lastTime > timeInterval) {
16        lastTime = millis();
17        data = BME.readTemperature();
18    }
19    return data;
20 }
21
22 int getMoisture(int probePIN, int timeInterval) {
23    static int lastTime = -999999;
24    static int data;
25
26    if(millis() - lastTime > timeInterval) {
27        lastTime = millis();
28        data = analogRead(probePIN);
29    }
30    return data;
31 }
```



STRUCT datatype and operators

struct enables the programmer to create a variable that structures a selected set of data.

```
struct name  
struct Employee {  
    char name[10];  
    int idNumber;  
    float salary;  
}  
  
Employee instructor;      } Declare individual variable of data type Employee  
Employee IoTEngineers[10]; } Declare an array of data type Employee  
  
void setup {  
    instructor.name = "Brian";  
    instructor.idNumber = "42";  
    instructor.salary = 212.47;  
    IoTEngineers[1].name = "Sally";  
}
```



STRUCT datatype and operators

struct creates a variable that structures a set of data.

```
1 struct GeoLocation {      // create a struct of name geo that hold GPS data
2   float lat;
3   float lon;
4   int alt;
5 }; // ends with a ; as struct can also declare variables while being declared
6
7 GeoLocation myLoc;        //declare a variable called myLoc of type geo
8 GeoLocation locations[13]; //declare an array of type geo
9
10 void setup() {
11   //initialize myLoc with latitude, longitude, and altitude
12   myLoc.lat = 35.120606;
13   myLoc.lon = -106.65818;
14   myLoc.alt = 1517;
15
16   Serial.printf("Location: lat %f, lon %f, alt %i \n",myLoc.lat,myLoc.lon,myLoc.alt);
17 }
```

The . (dot) operator and the – > (arrow) operator are used to reference individual members of structures.

- The dot operator is applied to the actual object.
- The arrow operator is used with a pointer to the object (we will learn about Pointers in Lesson 12).



JSON

JSON (JavaScript Object Notation) is a lightweight data-interchange format. It is easy for humans to read and write. It is easy for machines to parse and generate. It is based on a subset of the JavaScript Programming Language Standard ECMA-262 3rd Edition - December 1999. JSON is a text format that is completely language independent but uses conventions that are familiar to programmers of the C-family of languages, including C, C++, C#, Java, JavaScript, Perl, Python, and many others. These properties make JSON an ideal data-interchange language.

JSON is built on two structures:

- A collection of name/value pairs. In various languages, this is realized as an object, record, struct, dictionary, hash table, keyed list, or associative array.
- An ordered list of values. In most languages, this is realized as an array, vector, list, or sequence.



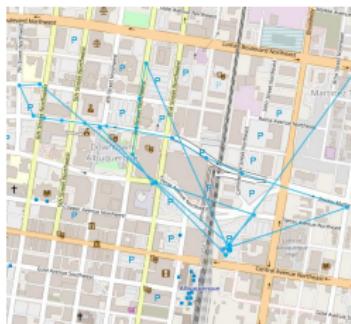
JSON Parser Generator

Creating objects in JSON are straightforward but can be tedious. There is a JSON Generator available to simplify the process.

```
1 #include "JsonParserGeneratorRK.h"
2
3 void createEventPayLoad(float tempValue, float presValue, float humValue) {
4     JsonWriterStatic<256> jw;
5     {
6         JsonWriterAutoObject obj(&jw);
7
8         jw.insertKeyValue("Temperature", tempValue);
9         jw.insertKeyValue("Pressure", presValue);
10        jw.insertKeyValue("Humidity", humValue);
11    }
12    Particle.publish("env-vals", jw.getBuffer(), PRIVATE);
13 }
```



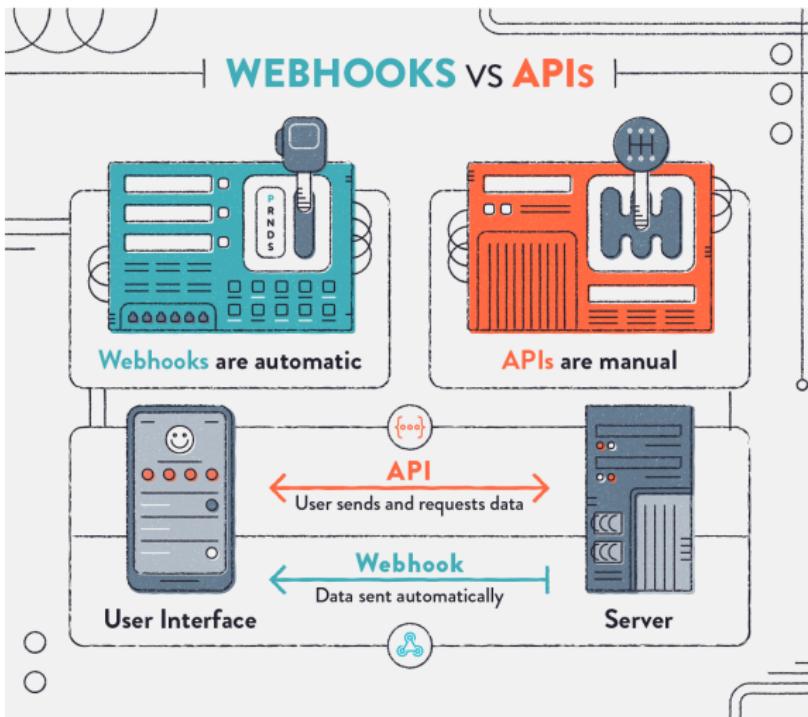
Assignment: L09_02_GPSPublish



- ① Create a STRUCT to hold a GPS location (latitude and longitude)
- ② Every 10 seconds (without using delays), generate random GPS coordinates within Albuquerque.
- ③ Create a function that has as a single parameter a GPS location STRUCT variable. The function should:
 - Create a JSON payload from the GPS coordinates members of the STRUCT.
 - Publish to Adafruit.io using MQTT and JSON format. Must use "lat" and "lon" as the names for the JSON data elements.
- ④ Using the Map block to create a dashboard that shows the GPS coordinates

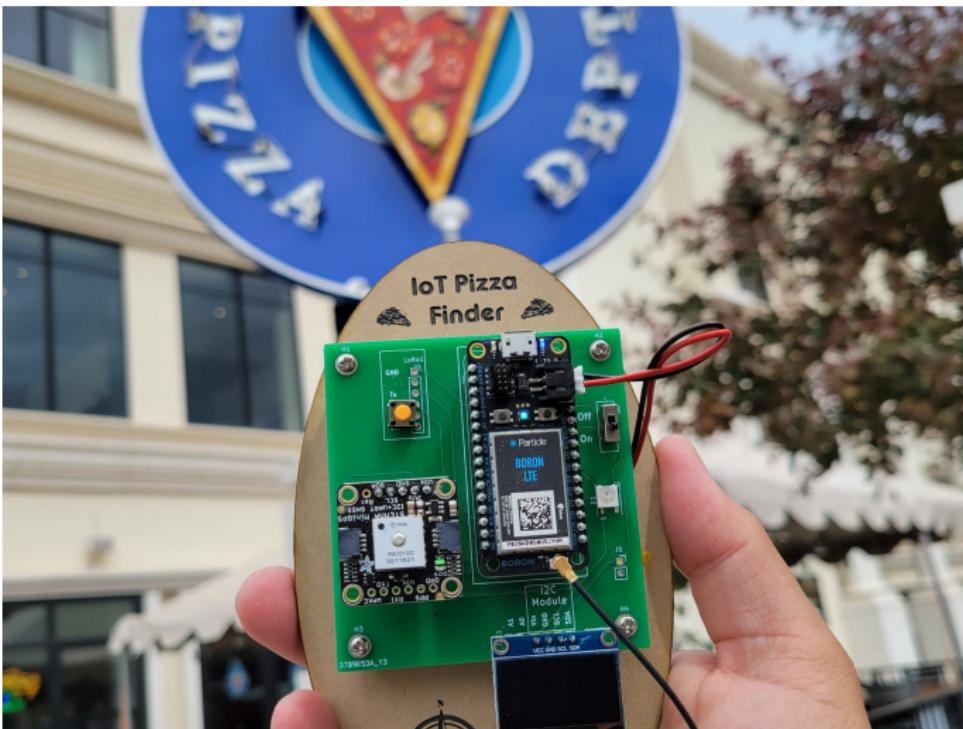


Webhooks





Pizza Finder





TomTom API

The screenshot shows the TomTom developer portal at <https://developer.tomtom.com/user/me/apps?category=1>. The page is titled 'KEYS'. It lists one API key:

Key	Value
My First API Key	sbBf.....KwA1

Next to the key value is a 'Detailed view' button and a black toggle switch.

Obtain a TomTom API key from

<https://developer.tomtom.com/user/register>



TomTom API Call

<https://api.tomtom.com/search/2/search/pizza.json?key=YOURKEY&lat=40.68353&lon=-73.92890&limit=1>

```
1 {"summary": {"query": "pizza", "queryType": "NON_NEAR", "queryTime": 115, "numResults": 1, "offset": 0, "totalResults": 99, "fuzzyLevel": 1, "geoBias": {"lat": 40.68353, "lon": -73.9289}, "queryIntent": [], "geobiasCountry": "US", "results": [{"type": "POI", "id": "qdKlmWa3zfaxQkqrL_gAjQ", "score": 0.9925668836, "dist": 76.561442, "info": "search:ta:840369014649111-US", "poi": {"name": "Sergio's Pizza", "phone": "+1 718-513-3300", "categorySet": [{"id": 7315036}], "url": "www.sergiosnypizza.com/brooklyn-ny/", "categories": ["pizza", "restaurant"], "classifications": [{"code": "RESTAURANT", "names": [{"nameLocale": "en-US", "name": "restaurant"}, {"nameLocale": "en-US", "name": "pizza"}]}]}, "address": {"streetName": "Malcolm X Boulevard", "municipalitySubdivision": "Brooklyn", "municipality": "New York", "countrySecondarySubdivision": "Kings", "countrySubdivision": "NY", "countrySubdivisionName": "New York", "postalCode": "11233", "extendedPostalCode": "11233-1117", "countryCode": "US", "country": "United States", "countryCodeISO3": "USA", "freeformAddress": "Malcolm X Boulevard, Brooklyn, NY 11233", "localName": "Brooklyn"}, "position": {"lat": 40.682841, "lon": -73.928898}, "viewport": {"topLeftPoint": {"lat": 40.68374, "lon": -73.93008}, "bottomRightPoint": {"lat": 40.68194, "lon": -73.92771}}, "entryPoints": [{"type": "main", "position": {"lat": 40.68281, "lon": -73.92904}}]}]}}}
```



JSON Viewer

<https://jsonviewer.stack.hu/>

Viewer Text

JSON

- summary
- results
 - 0
 - type : "POI"
 - id : "qdKlmWa3zfaxQkqrL_gAJQ"
 - score : 0.9925668836
 - dist : 76.561442
 - info : "search:ta:840369014649111-US"
 - poi
 - name : "Sergio's Pizza"
 - phone : "+1 718-513-3300"
 - categorySet
 - url : "www.sergiosnypizza.com/brooklyn-ny/"
 - categories
 - classifications
 - address
 - position
 - lat : 40.682841
 - lon : -73.928898
 - viewport
 - entryPoints



JSON Response Template - Mustache Tester

<http://rickkas7.github.io/mustache/>

Mustache Tester

Show me an example: -

Enter JSON data to parse:

```
{"summary":  
{"query":"pizza","queryType":"NON_NEAR","queryTime":115,"numResults":1,"offset":0,"totalResults":99,  
"fuzzyLevel":1,"geoBias": {"lat":40.68353,"lon":-73.9289}, "queryIntent":  
[], "geobiasCountry": "US"}, "results":  
[{"type": "POI", "id": "qdklmWa3zfaxQkqrL_gAjQ", "score": 0.9925668836, "dist": 76.561442, "info": "search:ta  
840369014649111-5", "poi": {"name": "Sergio's Pizza", "phone": "+1 718-513-3300", "categorySet":  
[{"id": 7315036}], "url": "www.sergionsypizza.com/brooklyn-ny", "categories":  
["pizza", "restaurant"], "classifications": [{"code": "RESTAURANT", "names": [{"nameLocale": "en-US", "name": "restaurant"}, {"nameLocale": "en-US", "name": "pizza"}]}]}, "address": {"streetName": "Malcolm  
Boulevard", "municipalitySubdivision": "Brooklyn", "municipality": "New
```

Show formatted JSON data

JSON data, formatted. Click on a row to generate the accessor to use:

```
{  
  "summary":  
  {  
    "query":"pizza",  
    "queryType":"NON_NEAR",  
    "queryTime":115,  
    "numResults":1,  
    "offset":0,  
    "totalResults":99.
```



Mustache Template Test

```
1 {"name": "{{results[0].poi.name}}", "plat": {{results[0].position.lat}}, "plon": {{results[0].position.lon}} }
```

Enter a mustache template to test:

```
{"name": "{{results[0].poi.name}}", "plat": {{results[0].position.lat}}, "plon": {{results[0].position.lon}} }
```

Processed template and data:

```
{"name": "Sergio's Pizza", "plat": 40.682841, "plon": -73.928898 }
```

Processed template and data, as formatted JSON:

```
{
  "name": "Sergio's Pizza",
  "plat": 40.682841,
  "plon": -73.928898
}
```



Particle Console Integrations

Sandbox | Docs | Try dark mode | Contact sales | Support | Notifications | barashap@gmail.com

Integrations

Filter by Name Name ▾ + ADD NEW INTEGRATION

Name	Event	Type	Target	Status	Today's traffic
bme-vals for thingspeak.com	bme-vals	Webhook	thingspeak.com	Enabled	none
env-vals for thingspeak.com	env-vals	Webhook	thingspeak.com	Enabled	none
FUSEMakerspace for thingspeak.com	FUSEMakerspace	Webhook	thingspeak.com	Enabled	none
GetWeatherData for openweathermap.org	GetWeatherData	Webhook	openweathermap.org	Enabled	6 0 0
Pizza from TomTom	PizzaFinderTomTom	Webhook	tomtom.com	Enabled	127 0 0
temp for thingspeak.com	temp	Webhook	thingspeak.com	Enabled	none



Create a new webhook

Sandbox

Docs | Try dark mode | Contact sales | Support | Notifications | barashap@gmail.com

Integrations > New Integration

Google Maps
Geolocate Particle devices via visible Wi-Fi access points or Cellular towers

Azure IoT Hub
Stream Particle device data into the Azure ecosystem

Google Cloud Platform
Tie into an enterprise grade suite of cloud-based data storage and analysis tools

Webhook
Push Particle device data to other web services in real-time



Create a new webhook

PARTICLE

WEBHOOK BUILDER CUSTOM TEMPLATE

Read the Particle webhook guide

Name ⓘ
Pizza from TomTom

Event Name ⓘ
PizzaFinderTomTom

URL ⓘ
<https://api.tomtom.com/search/2/search/pizza.json>

Request Type ⓘ
GET

Request Format ⓘ
Query Parameters

Device ⓘ
Any

Status ⓘ
Enabled



- Particle logo
- Code editor icon
- Cloud icon
- Microcontroller icon
- Cell phone icon
- Right arrow icon
- Wrench and gear icon
- Barcode icon
- Credit card icon
- Left arrow icon



Create a new webhook

Advanced Settings

For information on dynamic data that can be sent in any of the fields below, please visit our docs.

QUERY PARAMETERS

Default Custom

> x

> x

> x

> x

+ ADD ROW



Create a new webhook

WEBHOOK RESPONSES

Response Topic ⓘ
{{PARTICLE_DEVICE_ID}}/{{PARTICLE_EVENT_NAME}}

Error Response Topic ⓘ

Response Template ⓘ
{"plat":{{results.0.position.lat}},"plon":{{results.0.position.lon}},"name":"{{results.0.poi.name}}"}
6

ENFORCE SSL ⓘ

Yes No

CANCEL **SAVE**



Test your webhook

Integrations > View Integration

 Webhook	Name: Pizza from TomTom Event: PizzaFinderTomTom ID: 646f72c814d8df117a546302 Status: Enabled	Target: tomtom.com Created: May 25th, 2023 Updated: May 25th, 2023	<button>TEST</button> <button>EDIT</button> <button>DELETE</button>
---	--	--	---



Webhook Call and Subscription Handler

```
1 #include "Particle.h"
2 const char *EVENT_NAME = "PizzaFinderTomTom";
3 const float lat=40.69017, lon=-73.96359;
4 unsigned int lastTime;
5 void subscriptionHandler(const char *event, const char *data);
6 SYSTEM_MODE(AUTOMATIC); //must be in automatic for Particle publish/subscribe
7 void setup() {
8     String subscriptionName=String::format("%s/%s/",System.deviceID().c_str(),EVENT_NAME);
9     Particle.subscribe(subscriptionName,subscriptionHandler,MY_DEVICES);
10    Serial.printf("Subscribing to %s\n",subscriptionName.c_str());
11 }
12 void loop() {
13     if((millis() - lastTime) > 60000) {
14         Particle.publish(EVENT_NAME, String::format("{\"lat42\":%0.5f,\"lon42\":%0.5f}", 
15             lat, lon), PRIVATE);
16         lastTime = millis();
17     }
18 }
19 void subscriptionHandler(const char *event, const char *data) {
20     String pizzaName;
21     float lat,lon;
22     JSONValue outerObj = JSONValue::parseCopy(data);
23     JSONObjectIterator iter(outerObj);
24     while(iter.next()) {
25         if (iter.name() == "plat") lat = iter.value().toDouble();
26         if (iter.name() == "plon") lon = iter.value().toDouble();
27         if (iter.name() == "name") pizzaName = (const char *)iter.value().toString();
28     }
29     Serial.printf("Pizza found at %s (%0.6f,%0.6f)\n",pizzaName.c_str(),lat,lon);
}
```



Assignment: L09_03_WebHook



- ① Register and obtain your TomTom API key
- ② Call the TomTom API in a browser and view results in JSON Viewer and Mustache Template Builder
- ③ Create a webhook to find the closest pizza (or business of your choice)
- ④ Set the GPS coordinates to your favorite vacation location
- ⑤ Write Particle code to call your webhook and print the returned values to the screen.



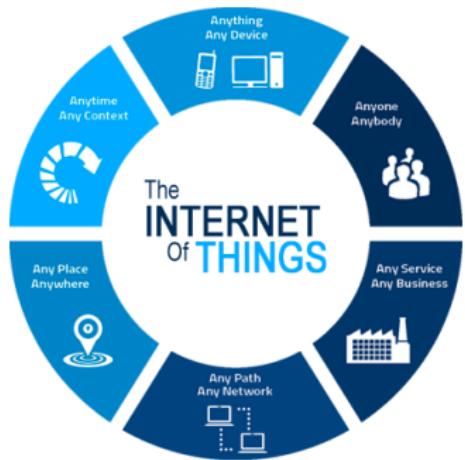
Assignment: L09_04_BusRoute (Extra Credit)



- ① Go to <https://data.cabq.gov/transit/realtime/route/> and get data for Route 777.
- ② Using <http://rickkas7.github.io/mustache/> find the Response Template that returns bus id and its location. Hint: first bus is 0, second is 1, etc.
- ③ Create a webhook to pull one of the bus's location onto the Particle.
- ④ Calculate the distance of the bus from FUSE and display to OLED.



Module 9 Review

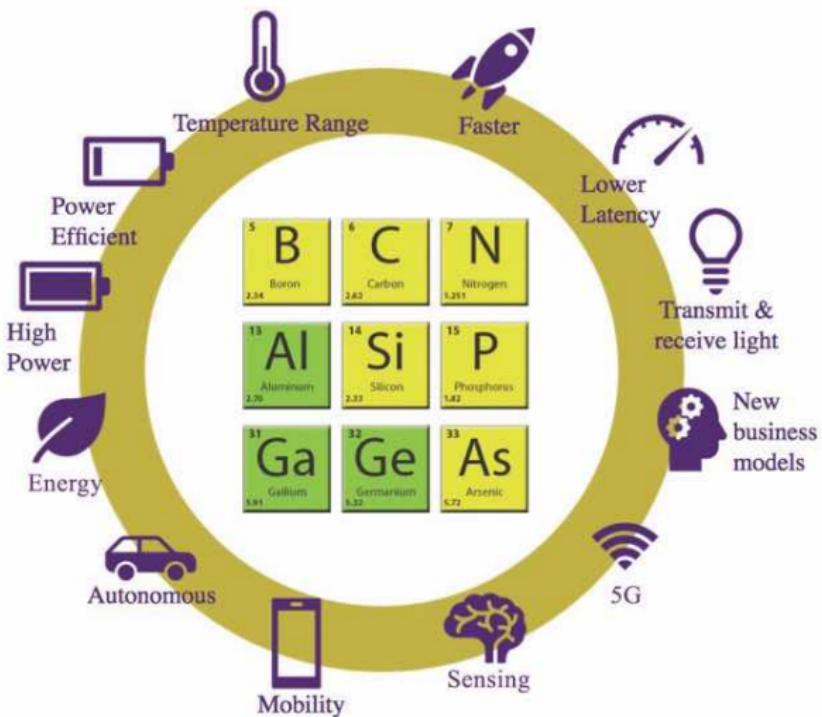


- Learning Objectives
 - ① Communicating to the cloud using MQTT
 - ② Javascript Object Notation (JSON)
 - ③ Webhooks
- Additional Items
 - ① 3D Modeling Lesson 4 - Tubes
 - ② Quiz 6

Module 10 - Semiconductors

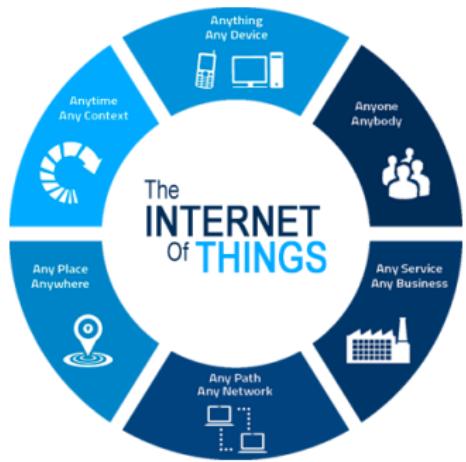


Semiconductors





Module 10 Objectives



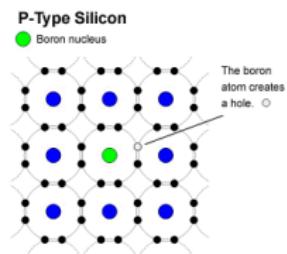
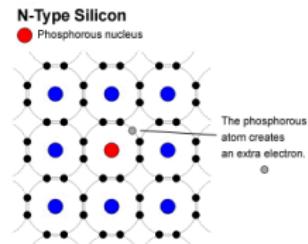
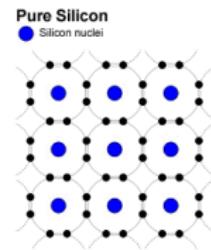
- Learning Objectives

- 1 Semiconductors
- 2 Diodes
- 3 Transistors
- 4 Amplifiers



Semiconductor

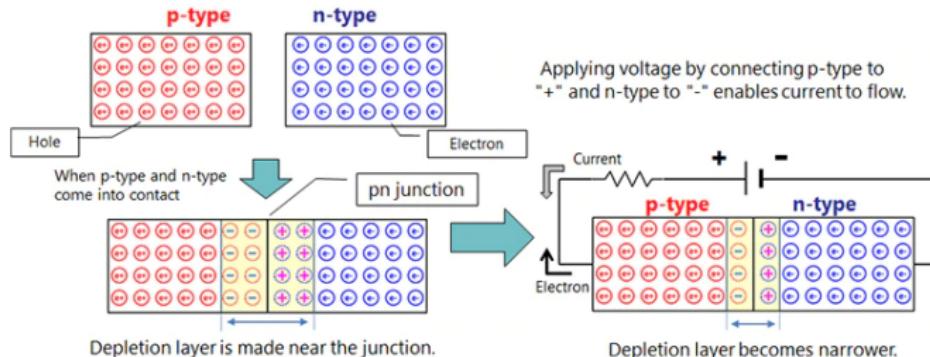
- A silicon atom has four electrons in its outer shell and bonds tightly with four surrounding silicon atoms creating a crystal matrix with eight electrons in the outer shells. The tight bonds make pure silicon non-conducting.
- Phosphorus has five electrons, and when combined, the fifth electron becomes a "free" electron that moves easily within the crystal when a voltage is applied.
- Boron has only three electrons in its outer shell and can bond with only three of surrounding silicon atoms. Thus one silicon atom has a vacant location in its outer shell, called a "hole," that readily accepts an electron.





pn junction diode

- When p-type and n-type semiconductors are bonded, holes and free electrons are attracted, combine, and disappear near the boundary. Since there are no carriers in this area, it is called a depletion layer and it is an insulator.
- A positive voltage applied to the p-type region causes electrons to flow sequentially from the n-type. The electrons will first disappear by combining with holes, but excess electrons will move to the positive pole and current will flow.





The story of the Blue LED

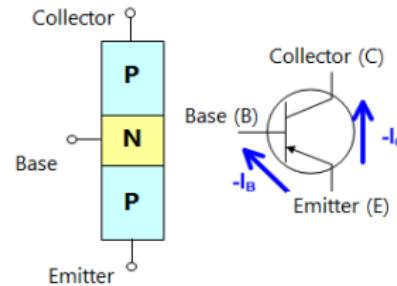
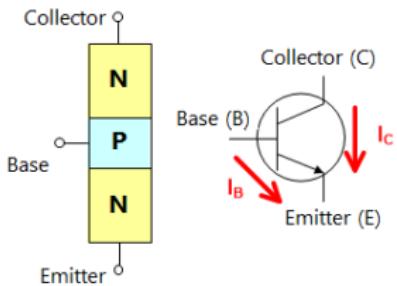


<https://youtu.be/AF8d72mA41M?si=dGNIvEEUrIV7rAS0>



Bipolar Junction Transistor

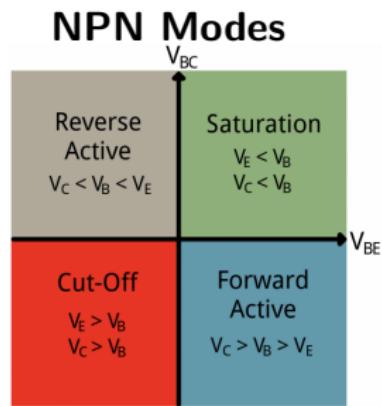
The transistor has three regions, namely base, emitter and collector. The emitter is a heavily doped terminal and emits electrons into the base. The base terminal is lightly doped and passes the emitter-injected electrons on to the collector. The collector terminal is intermediately doped and collects electrons from base. This collector is large as compared with other two regions so it dissipates more heat.





Bipolar Junction Transistor - Modes of Operation

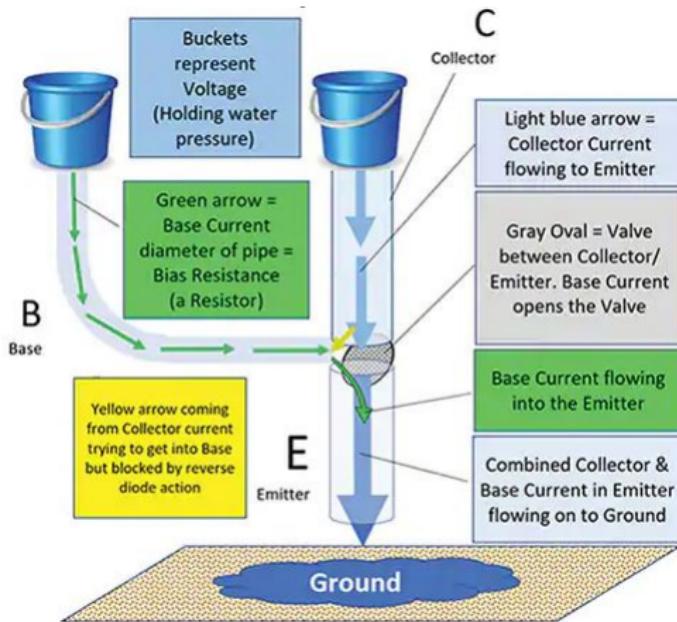
- **Saturation:** Current freely flows from collector to emitter. (ON Switch)
- **Cut-off:** No current flows from collector to emitter. (OFF Switch)
- **Active:** The current from collector to emitter is proportional to the current flowing into the base. (Amplifier)
- **Reverse-Active:** Like active mode, the current is proportional to the base current, but it flows in reverse from emitter to collector (not the purpose transistors were designed for).



Voltage relations	NPN Mode	PNP Mode
V _e < V _b < V _c	Active	Reverse
V _e < V _b > V _c	Saturation	Cutoff
V _e > V _b < V _c	Cutoff	Saturation
V _e > V _b > V _c	Reverse	Active



Water Analogy

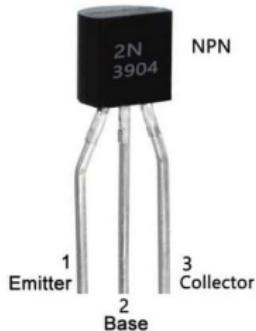




BJT Transistor Pinouts

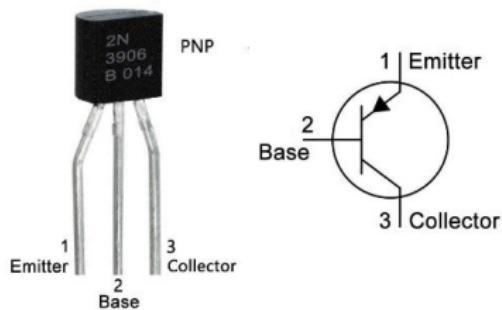
2N3904 NPN Transistor

TO-92 Package



2N3906 PNP Transistor

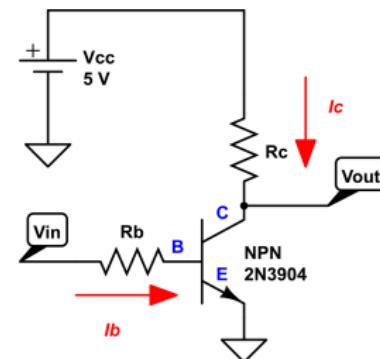
TO-92 Package





Active Mode NPN Transistor Circuit

If you apply a voltage V_{IN} that is high enough to forward-bias the base-to-emitter junction, current (I_B) will flow from the input terminal, through R_B , through the BE junction, to ground. Current (I_C) will also flow through R_C and the collector-to-emitter portion of the transistor.



NOTE: V_{OUT} is an amplified but inverted signal of V_{IN} .

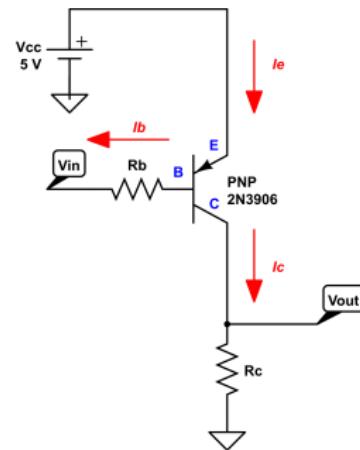
This simple circuit will step-up a 0 - 3.3V output from the microcontroller to 0 - 5.0V (inverted). The low impedance of the output will also provide sufficient current to drive a higher current device (e.g., a relay).



PNP Transistor

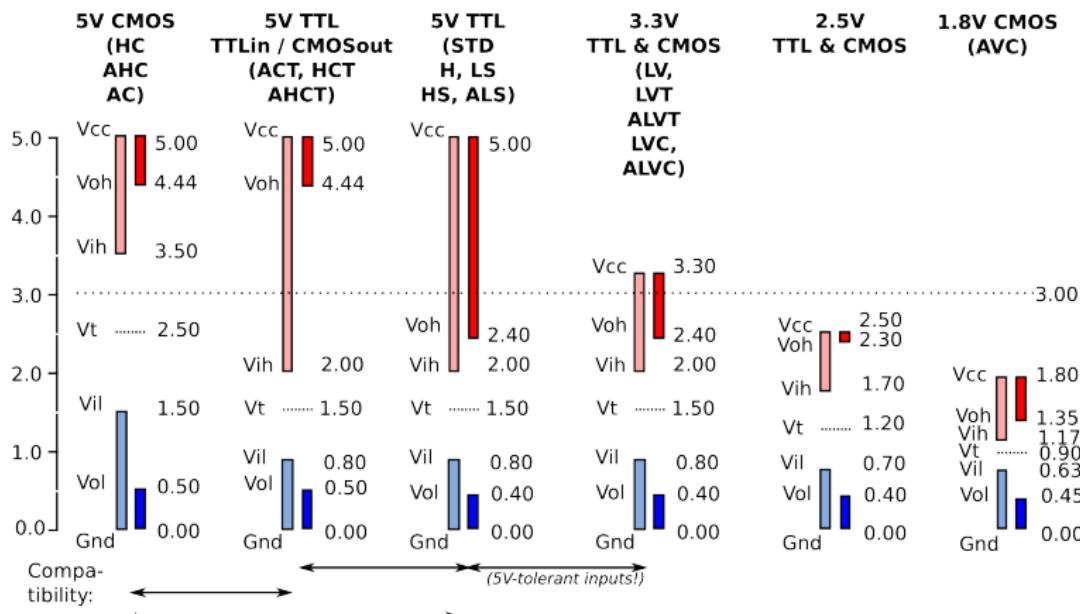
NPN Transistors are more common than PNP for a number of reasons:

- The voltage and current behavior of an NPN transistor is significantly more intuitive.
- When a switch or driver circuit is required, NPNs provide a more straightforward interface to digital output signals (such as a control signal generated by a microcontroller).
- NPNs are higher performance (faster switching speeds) due to higher mobility of electrons vs holes.





Logic Voltage Level Standards



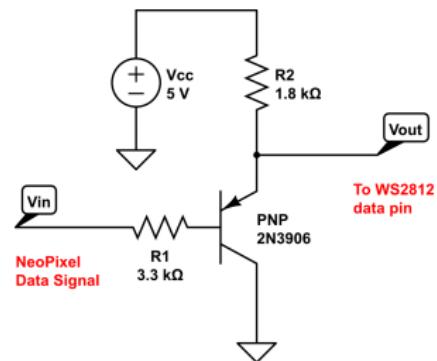
Data source: EETimes, A brief recap of popular logic standards (Mark Pearson, Maxim).

Or, what is wrong with the NeoPixels.



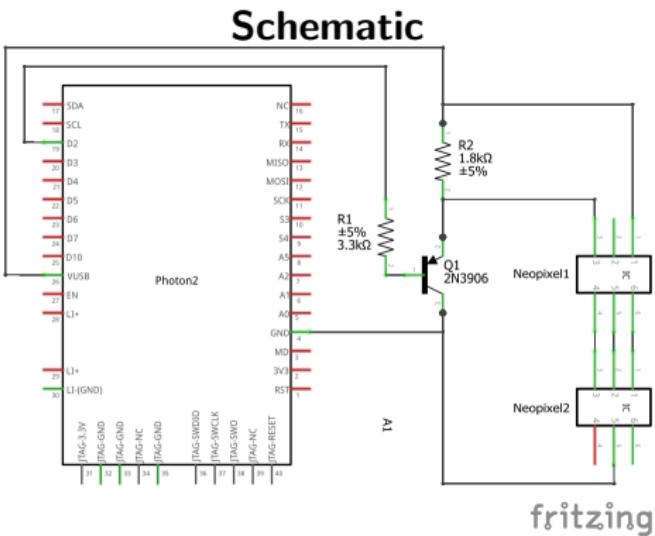
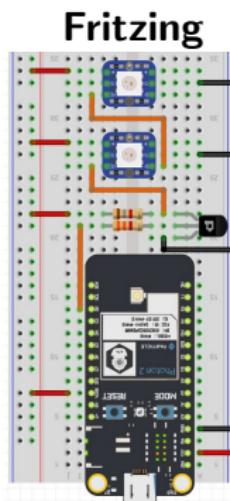
Emitter Follower - Saturation and Cutoff Mode

- NeoPixels are designed around 5V CMOS transistors.
 - $V_{IH} > 3.5V$
 - 3.3V Microcontroller
 - $V_{OH} = 3.3V$
- An Emitter Follower (i.e., a PNP transistor wired backwards) is a current amplifier, but will also produce a $V_{OUT} = 3.9V$.
- Alternatively, the first NeoPixel could be sacrificed by reducing its V_{cc} to 4.3V with a diode.



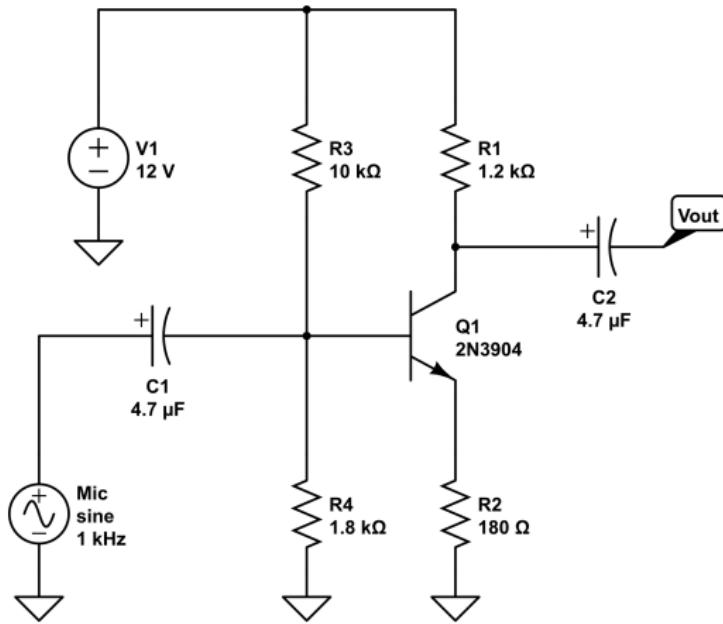


Emitter Follower Layout (using 2N3906 PNP Transistor)





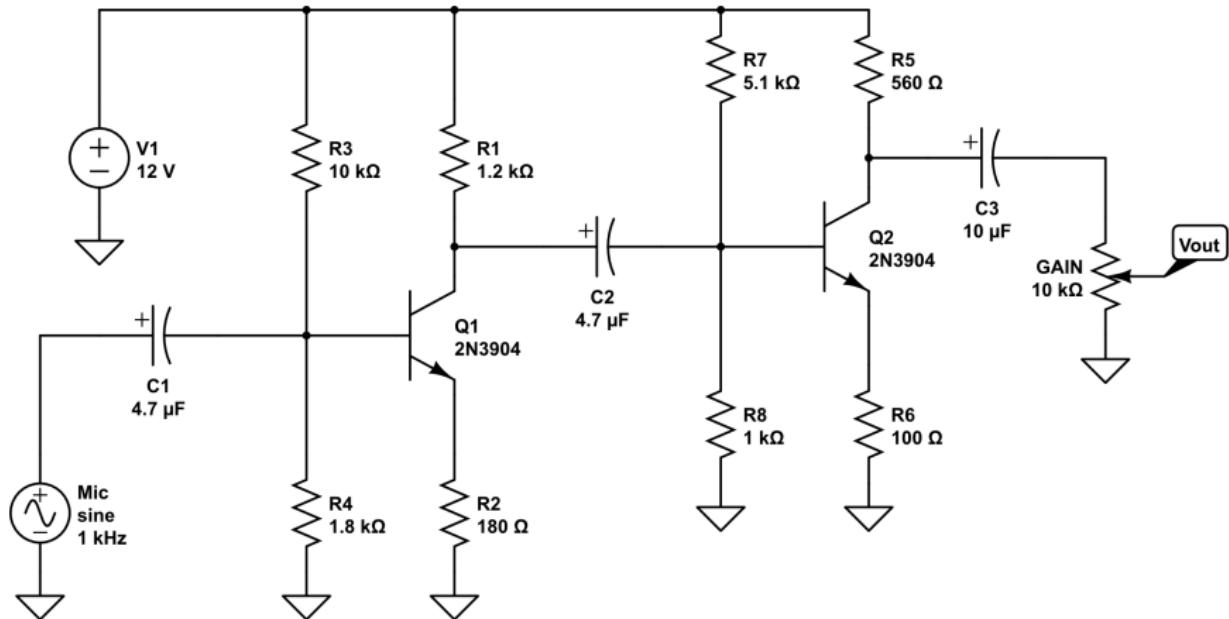
Typical NPN Pre-Amplifier Circuit



This is referred to as a Common Emitter amplifier as the Emitter ground is common to both the input and output voltage. The Common Emitter amplifies both voltage and current.

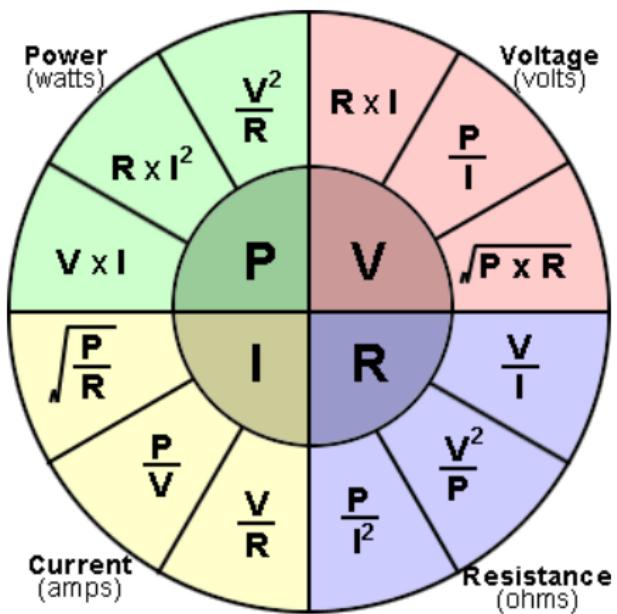


Two Stage Pre-Amplifier





Ohm's Law - Revisited





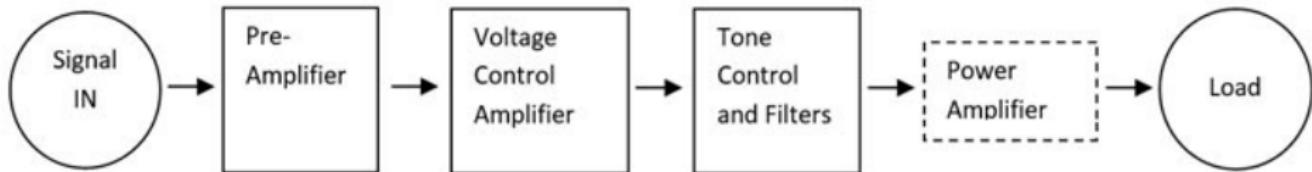
PreAmp vs PowerAmp

PreAmp:

- A preamp boosts the signal up to 'line level'.
- Guitar PreAmp
 - A pure guitar signal typically sounds weak and anaemic, as is seen if a guitar is directly plugged PA system.
 - A preamp is able to raise a guitar's signal up to an audible volume.
 - It can also be used to affect the audio characteristics.

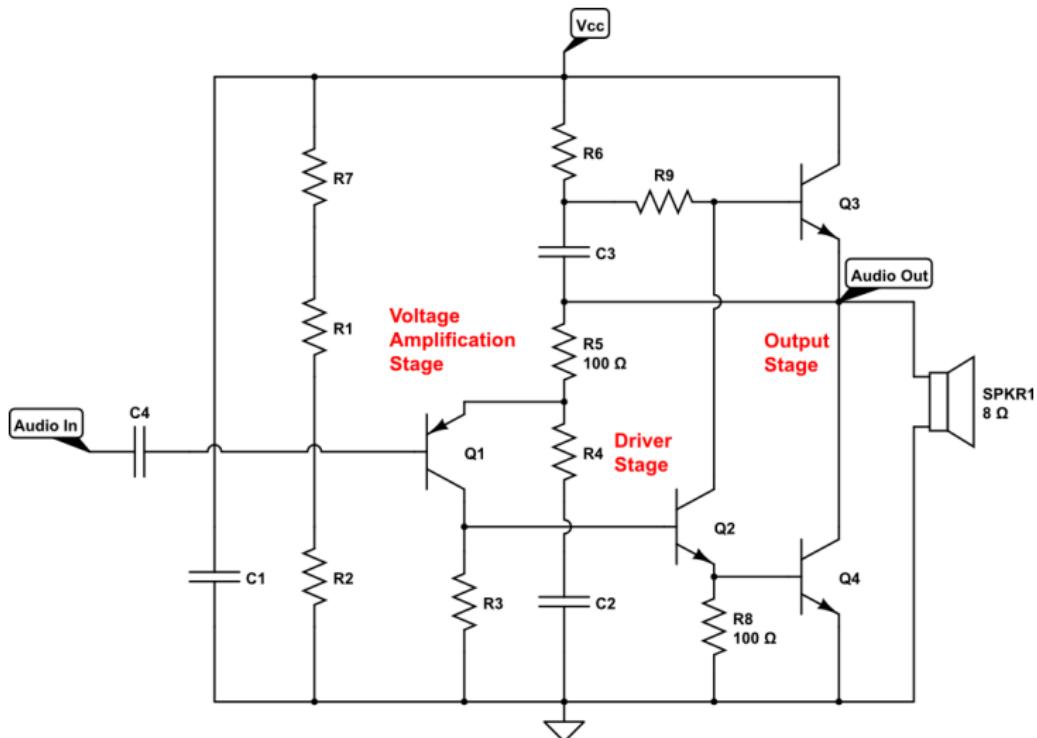
PowerAmp:

- A power amp boosts that line level signal even more – so that it can be projected through speakers.





Power Amplifier

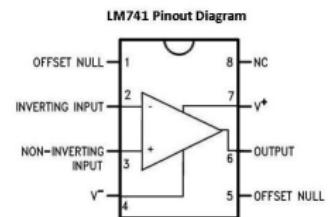
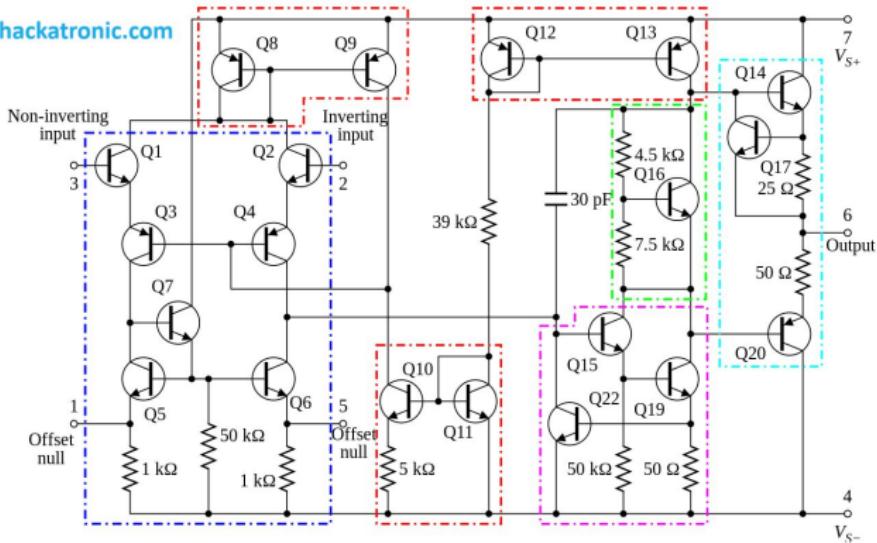




Operational Amplifiers or Op Amps

Integrated Circuit amplifier such as the LM741.

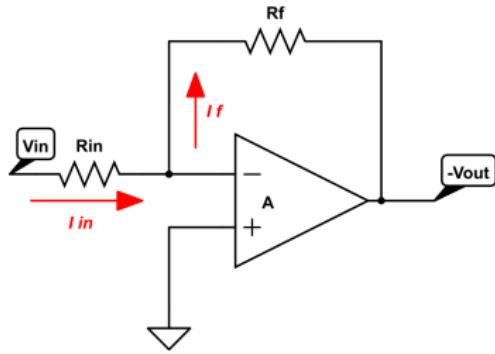
hackatronic.com



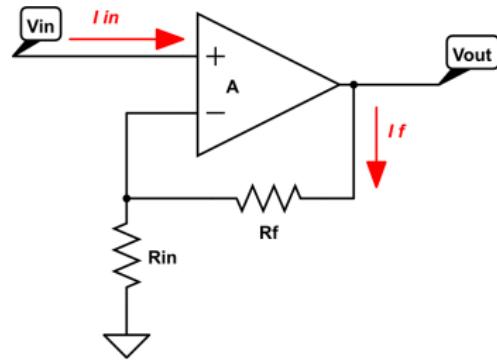


Op Amp Circuits

Inverting Op Amp



Non-inverting Op Amp



$$A = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

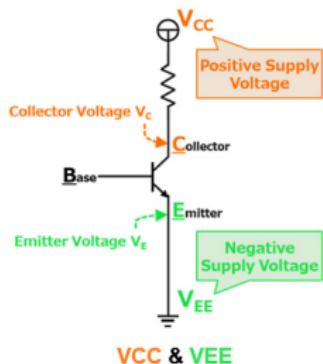
$$A = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_{in}}$$

Power the OpAmp with $V^+ = 12V$ and $V^- = 0$

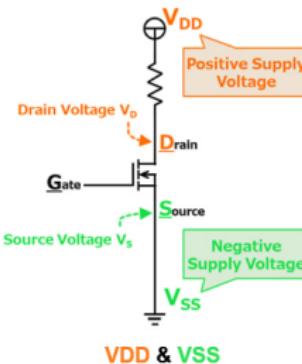


A word about Supply Voltage Designations

Bipolar Junction Transistors



Metal Oxide Semiconductor Field Effect Transistor (MOSFET)



Supply Voltage Designations:

- Positive Supply Voltage: (V_{cc} or V_{dd}) is equal to V_{in} or V^+ .
- Negative Supply Voltage: (V_{ss} or V_{ee}) is equal to GND or V^- .



Assignment: L10_Semiconductor

1 L10_01_NeoPixel

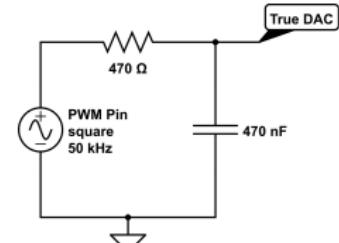
- Add a Emitter-Follower into your NeoPixel circuit to boost the pixel commands to 5V. Test with L04_01_NeoPixel.

2 L10_02_OpAmp

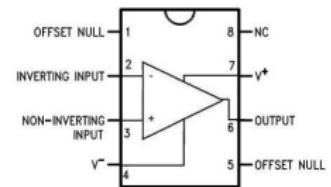
- Using the DAC and code from L05_00_lowPass to create a sine wave output (reduce the amplitude from 127.5 to 30).
- Amplify the True DAC output with a non-inverting LM741 Op Amp. Use a potentiometer for R_{in} .
- Measure the True DAC and Post-OpAmp signals with an oscilloscope.

3 L10_03_NPNamp

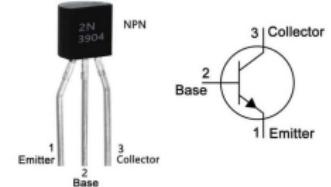
- Amplify using an NPN preamp instead.
- Measure the circuit at each node using the oscilloscope.



LM741 Pinout Diagram



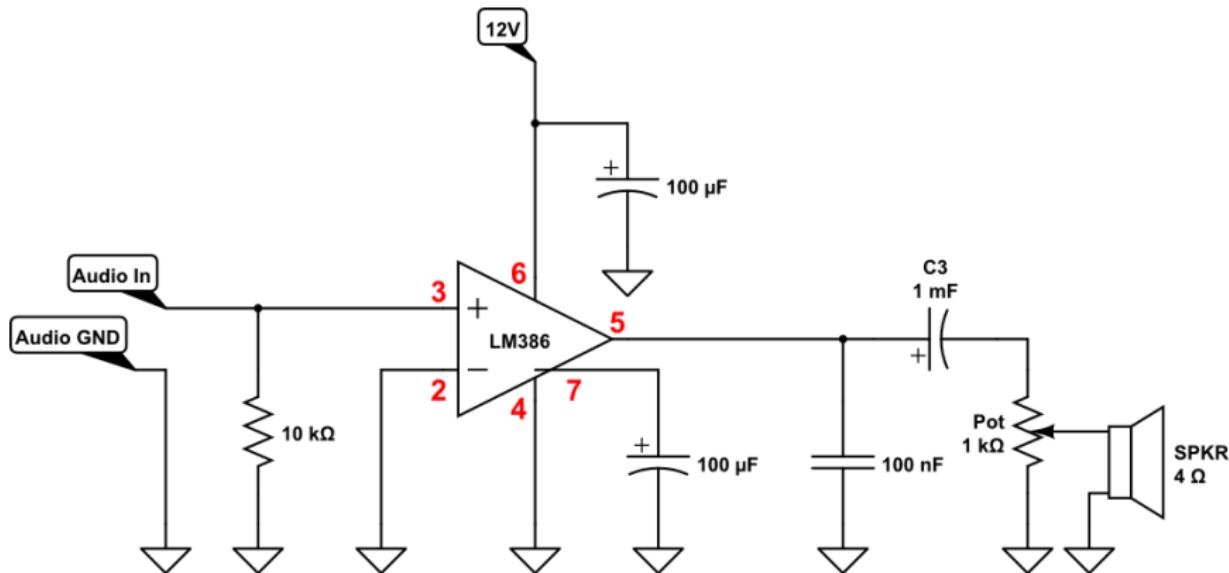
TO-92 Package





L10_04_AudioAmp (Extra Credit)

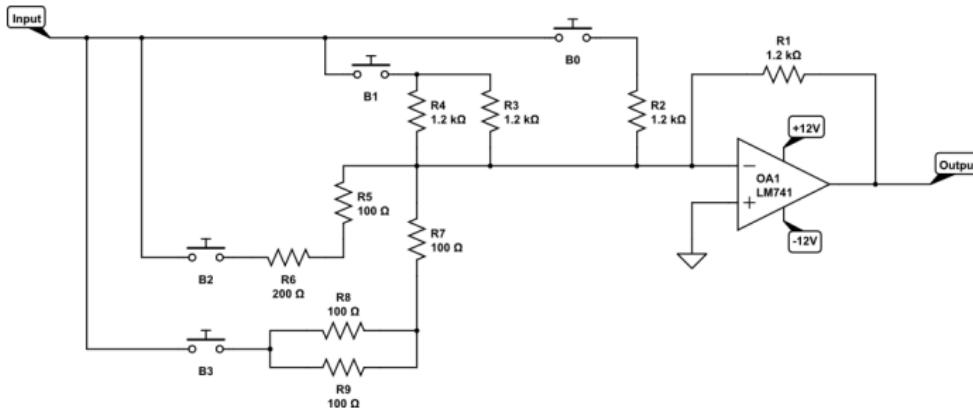
The LM386 is specifically designed for use in audio applications. Its performance is based on driving speakers



- Build the circuit, test with signal generator and oscilloscope.
- Then, hook up sound from phone and speaker



L10_05_MysteryCircuit (Extra Credit)

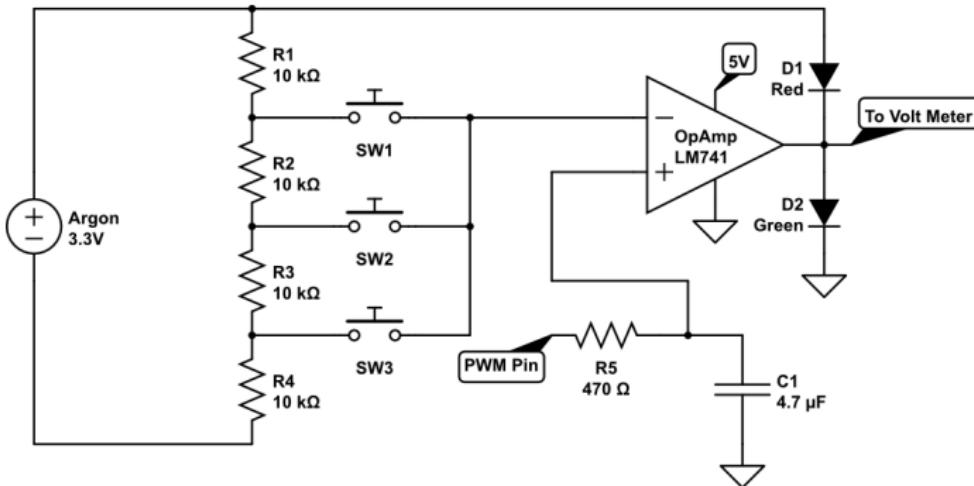


- Layout circuit in Fritzing - there is no Particle in this circuit
- Build and test circuit with input at Oscilloscope station
- Record output voltage for all combinations of buttons presses
- Figure out what it is doing and why it works.

Power the OpAmp with $V^+ = 12V$ and $V^- = -12V$



L10_06_MysteryCircuit2 (Extra Credit)

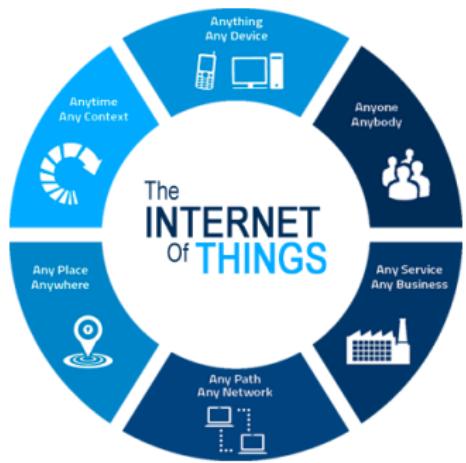


- Set analogWrite frequency to 50k
- AnalogWrite 1.8V and see the result of different button presses.
- Try different analogWrite voltages

Power the OpAmp with $V^+ = 12V$ and $V^- = 0V$



Module 10 Review



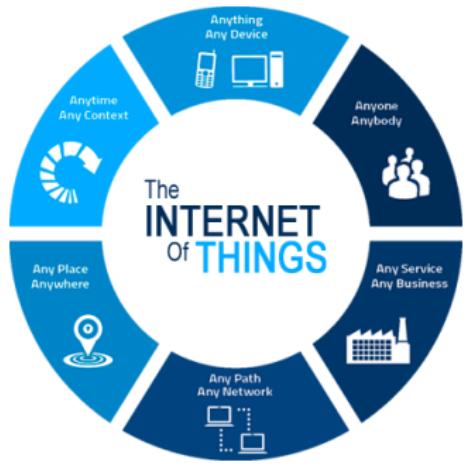
- Learning Objectives

- 1 Semiconductors
- 2 Diodes
- 3 Transistors
- 4 Amplifiers

Module 11 - Sensors



Module 11 Objectives



- Learning Objectives

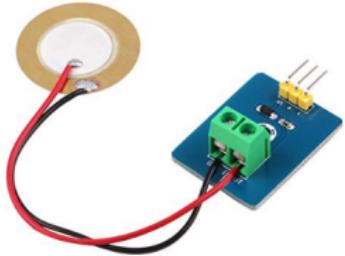
- ➊ Piezoelectric Elements
- ➋ Load Cells
- ➌ Moisture Sensors
- ➍ New sensors - learning on your own
- ➎ String datatype

- Additional Items

- ➊ 3D Modeling Lesson 5 - IoT Case
- ➋ Quiz 7



Piezoelectric Elements



- The piezoelectric effect is the creation of electrical potential (voltage) across the side of a crystal when subject to mechanical stress.
- Conversely, a crystal becomes mechanically stressed (deformed in shape) when a voltage is applied across opposite faces.
- By utilizing an `analogRead()`, the voltage (and thus the amount of pressure on the crystal) can be measured.



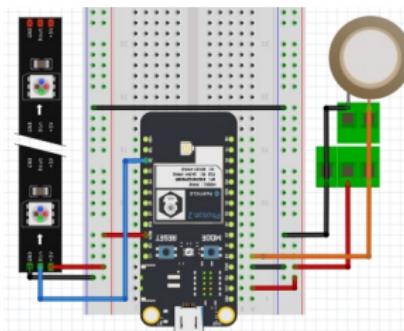
Assignment: Carnival Game



① L11_01_HighStriker

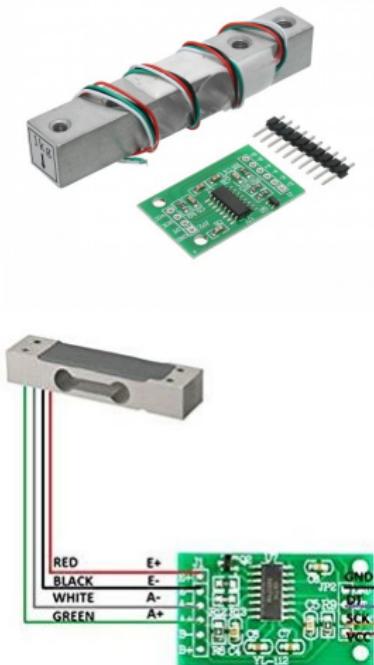
- Connect the piezo sensor and the NeoPixel tower to the Particle
- Each time the piezo is struck, find the maximum voltage generated.
- Light up the NeoPixel tower proportional to the force the piezo is struck with.
- Small delay ($< 150ms$) is allowed to create the moving effect as the tower lights up.

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code





Load Cells

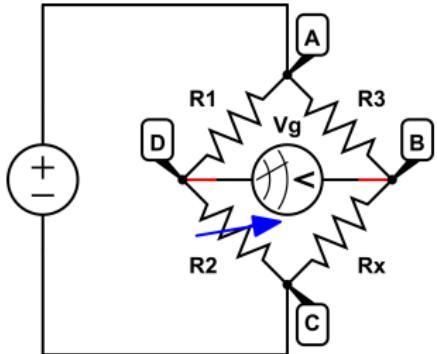


- ① A load cell is a force transducer. It converts a force such as tension, compression, pressure, or torque into an electrical signal that can be measured and standardized. As the force applied to the load cell increases, the electrical signal changes proportionally. The most common types of load cells used are hydraulic, pneumatic, and strain gauge.
- ② The HX711 module is a precision 24-bit analog-to-digital converter (ADC) designed for weigh scales and industrial control applications to interface directly with a bridge sensor.



Wheatstone Bridge

- ① The Wheatstone bridge was invented by Samuel Hunter Christie in 1833 and improved and popularized by Sir Charles Wheatstone in 1843.
- ② A Wheatstone bridge is an electrical circuit used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component.
- ③ The primary benefit of the circuit is its ability to provide extremely accurate measurements (in contrast with something like a simple voltage divider).





HX711A Library - Linear Conversion

The Load Cell Library (HX711A) will convert the input into everyday units.

- `tare()`: The zero'ing function will automatically set the OFFSET
- `CALFACTOR`: This is used to convert from the 24-bit integer to units of your choice (grams, pounds, tons, etc.)

The HX711 Class will automatically convert the measured value (minus the OFFSET) to desired units using CALFACTOR:

$$\text{units} = \frac{1}{\text{CALFACTOR}} * (\text{value} - \text{OFFSET})$$

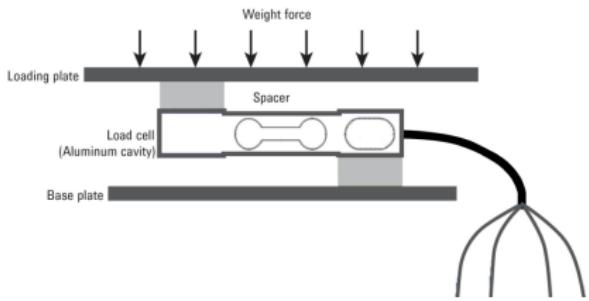


HX711A Library

```
1 // From the Command Palette install the HX711A library, that will give you HX711.h
2 #include "HX711.h"
3 HX711 myScale(DT,CLK);      // any two digital pins
4
5 const int CALFACTOR=1000; //changing value changes get_units units (lb, g, ton, etc.)
6 const int SAMPLES=10; //number of data points averaged when using get_units or get_value
7
8 float weight, rawData, calibration;
9 int offset;
10
11 void setup() {
12   myScale.set_scale();           // initialize loadcell
13   delay(5000);                 // let the loadcell settle
14   myScale.tare();               // set the tare weight (or zero)
15   myScale.set_scale(CALFACTOR); //adjust when calibrating scale to desired units
16 }
17
18 void loop() {
19   // Using data from loadcell
20   weight = myScale.get_units(SAMPLES); // return weight in units set by set_scale();
21   delay(5000)                         // add a short wait between readings
22
23   // Other useful HX711 methods
24   rawData = myScale.get_value(SAMPLES); // returns raw loadcell reading minus offset
25   offset = myScale.get_offset();        // returns the offset set by tare();
26   calibration = myScale.get_scale();   // returns the cal_factor used by set_scale();
27 }
```



Assignment: L11_Sensor (Learn to Calibrate)



① L11_02_Scale

- The LoadCell must be cantilevered similar to the diagram. Using the Epilog Laser or the Wood/Metal shop, create a method to cantilever your scale.
- Set initial CALFACTOR to 1000 and measure a known weight. (Note: one cup of water (in a paper cup) is approx. 244 g).
- Adjust CALFACTOR until you get the expected measurement in grams.
- Post data to Adafruit.io
- Extra Credit: Send text via IFTTT. There is an Adafruit → IFTTT example in Class_Materials.

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code



More DataTypes - Strings, strings, and char[]

```
1 // A string (lowercase 's') is an array of characters
2 char lastName[7] = "Rashap";
3 char firstName[6] = {'B', 'R', 'I', 'A', 'N'};
4 char name[12];
5
6 //The "*" indicates a pointer, which we will learn about later
7 char *myName = "Brian";
8
9 // A String is a Class that holds a character array
10 String instructor = "BRIAN RASHAP";
11
12 void setup() {
13   Serial.begin();
14
15   Serial.printf("lastName = %s, %i\n", lastName, sizeof(lastName));
16   Serial.printf("firstName = %s, %i\n", firstName, sizeof(firstName));
17   Serial.printf("name = %s, %i\n", name, sizeof(name));
18   Serial.printf("myName = %s, %i\n", myName, sizeof(myName));
19
20   // We can not use %s for the variable instructor, why?
21 }
```

```
Serial monitor opened successfully:
lastName = Rashap, 7
firstName = BRIAN, 6
name = , 12
myName = Brian, 4
```



Too Much Time On My Hands

When the Particle Photon2 connects to the Particle Cloud, it synchronizes its clock to the current time.

```
1 // Declare Global Variables in Header
2 String dateTime, timeOnly;
3 unsigned int lastTime;
4
5 void setup() {
6     Time.zone(-7);           // MST = -7, MDT = -6
7     Particle.syncTime();    // Sync time with Particle Cloud
8 }
9 void loop() {
10    dateTime = Time.timeStr();           //Current Date and Time from Particle Time class
11    timeOnly = dateTime.substring(11,19); //Extract the Time from the DateTime String
12    if(millis()-lastTime>10000) {
13        lastTime = millis();
14
15        //%s prints an array of char
16        //the .c_str() method converts a String to an array of char
17        Serial.printf("Date and time is %s\n",dateTime.c_str());
18        Serial.printf("Time is %s\n",timeOnly.c_str());
19    }
20 }
```

To learn more about the String Class: <https://docs.particle.io/reference/device-os/api/string-class/string/>

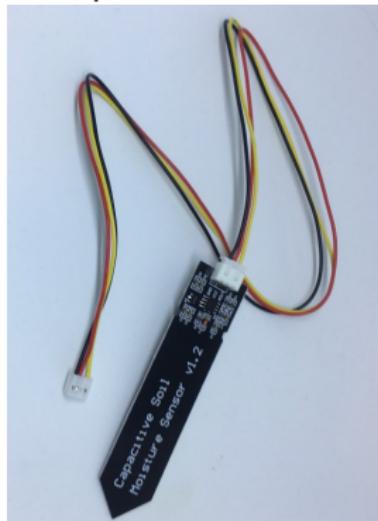


Soil Moisture Sensors

Resistive Sensor



Capacitive Sensor





Assignment: Moisture Probe



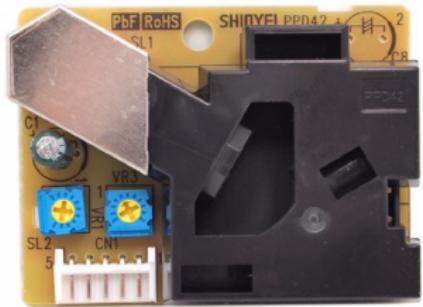
① L11_03_Moisture

- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- Using the Capacitive Soil Moisture probe, in your notebook note the moisture readings when:
 - Empty Cup
 - Submerged in water to the notch
 - Dry Soil
 - Soil after watered
- Display the moisture to the OLED with a Time-stamp.



Seeed Sensors



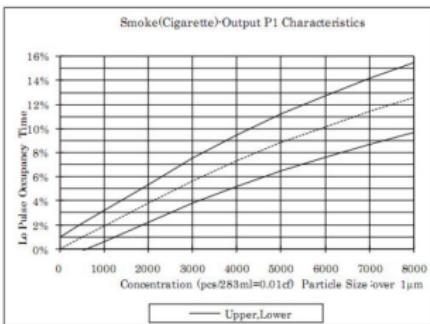
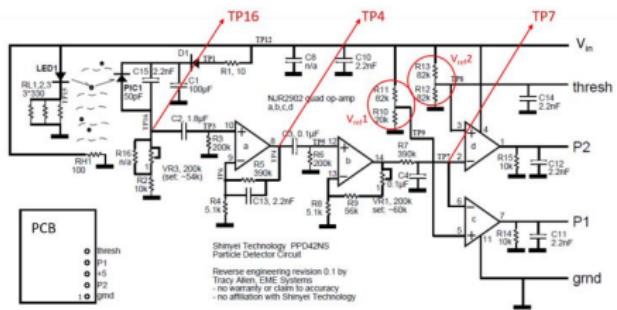
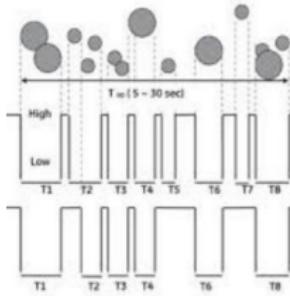
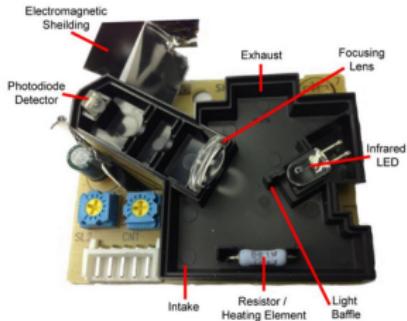
Seeed Grove - Dust Sensor



Seeed Grove - Air Quality
Sensor v1.3

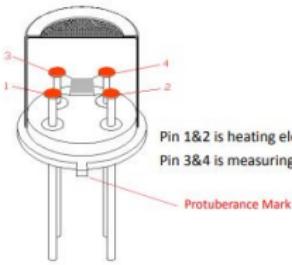


Shinyei PPD42NS low-cost dust sensor

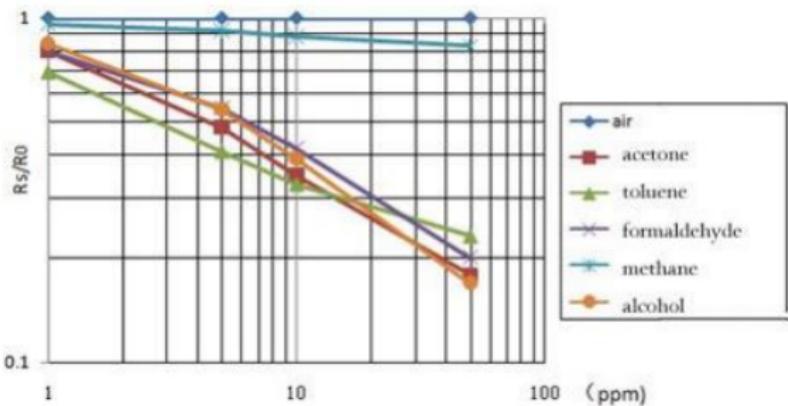




MP-503 Air Quality Sensor



Pin 1&2 is heating electrode,
Pin 3&4 is measuring electrode.





Seeed Assignment



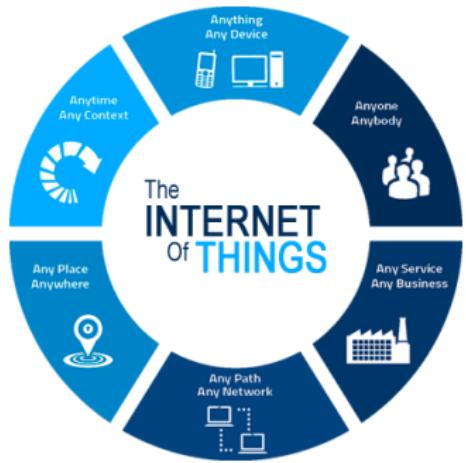
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

① L11_04_SeedSensors

- Look up the Seeed sensors online to see how they work.
- Do not blindly copy the examples. Only use the code you need.
- By looking at the .cpp code, determine how to get a quantitative value for air quality, in addition to the qualitative level.
- Display air quality and particulate concentration to an Adafruit.io dashboard.



Module 11 Review



Learning Objectives

- ① Piezoelectric Elements
- ② Load Cells
- ③ Moisture Sensors
- ④ New sensors - learning on your own
- ⑤ String datatype

Additional Items

- ① 3D Modeling Lesson 5 - IoT Case
- ② Quiz 7

Midterm 2 - House Plant Watering System



Not Everything is About Voltage

There is often a focus on voltage, it is possible to be current limited.

Parameter	Symbol	Min	Typ	Peak	Unit
Operating Current (uC on, peripherals and radio disabled)	I_{idle}	21.4	23.2	23.8	mA
Operating Current (uC on, BLE advertising)	I_{ble_adv}	54.7	58.7	70.7	mA
Operating Current (uC on, radio connected to access point)	$I_{wifi_conn_ap}$	54.6	60.5	265	mA

The 3.3V regulator can supply 500mA. Typical power consumption:

- The Photon2 connected to Wifi can draw up to 265mA.
- Each GPIO used as an output can supply 4 – 12mA.
- Each NeoPixel uses up to 60mA at full brightness.
- Seeed sensors: dust - 90mA, AQ sensor - 60mA
- Plant Watering Pump: 130mA

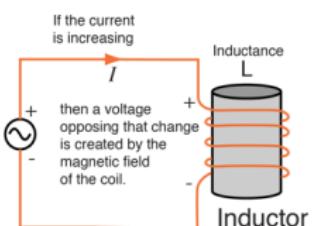
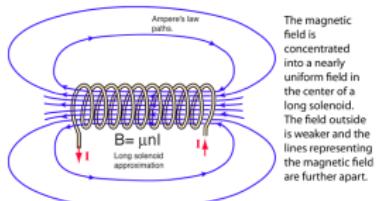
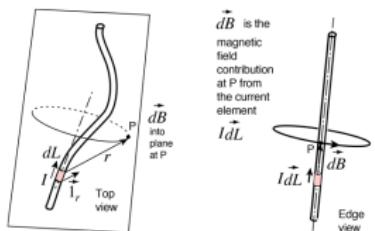
V_{USB} can supply¹ up to 1500mA². External supply can add more current.

¹It is all about power ($P = V * I$), so 1500mA at 5V is 2250mA at 3.3V

²Specific amount depends on type of USB port used (2.0 vs 3.x vs USB-C)



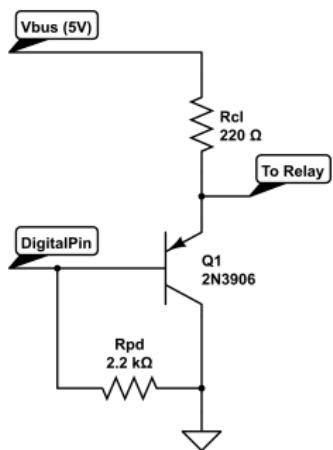
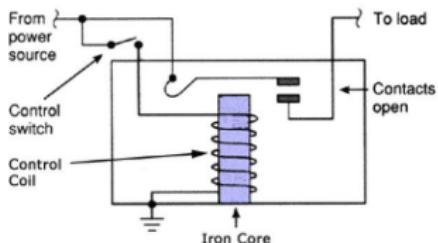
Inductors



- Current flowing in a wire produces a magnetic field (B) around the wire (from Ampere's Law).
- Wire wrapped into a coil produces a magnetic field that resembles a bar magnet through the center of the coil.
- Also, in a coil, this magnetic field produces an effect known as Inductance (L) that opposes changes in electric current.



Relays



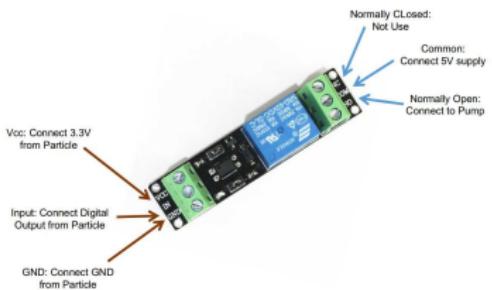
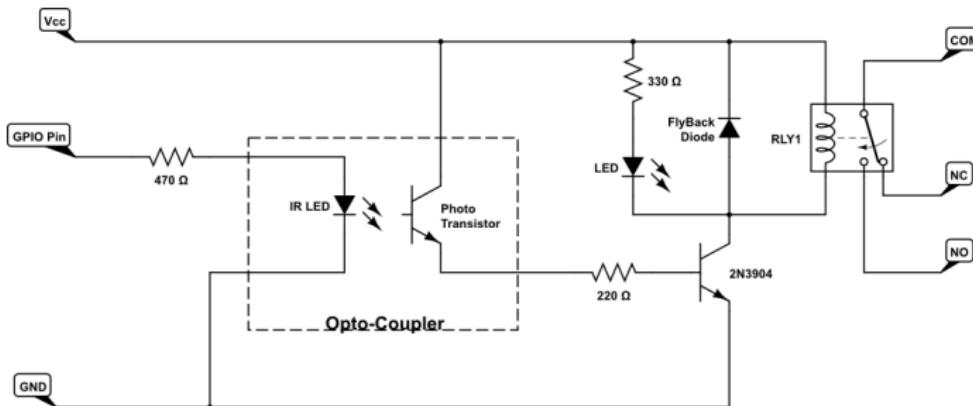
- When a device (e.g. a pump) requires higher voltage ($> 5V$) or higher current, then a relay can be used as a switch for the device

- The relay is activated by a digital pin from the microcontroller.

- As the relay can require as much as 100mA from the digital pin, to provide sufficient current, use a current amplifying emitter follower to draw current directly from the USB connection (V_{BUS}).



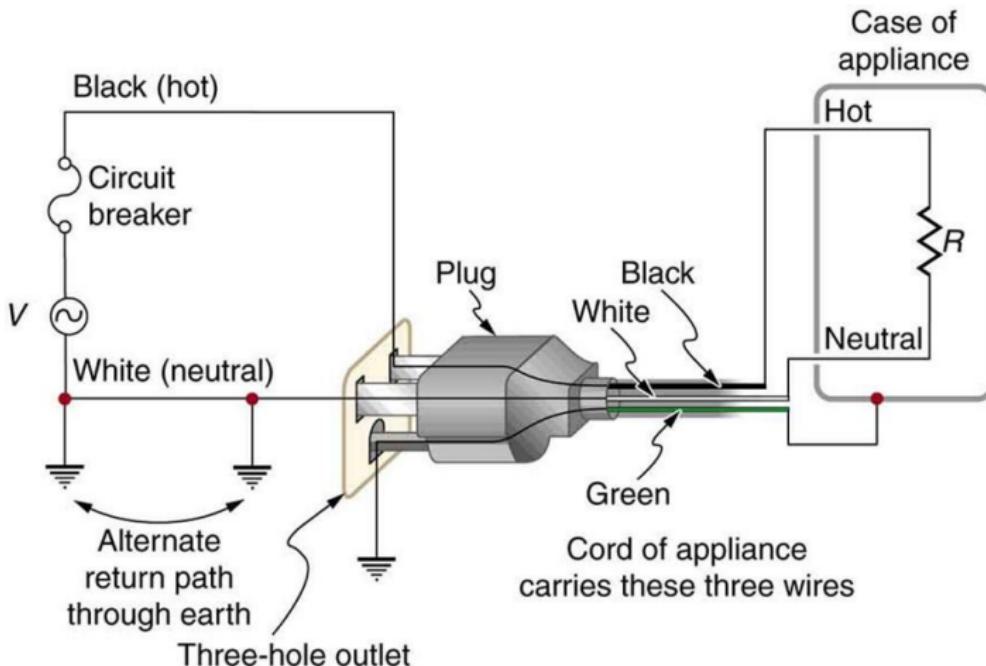
Optocoupled Relay



- Optocoupler isolates the relay load (which could be up to 240V) from the microcontroller electronics.

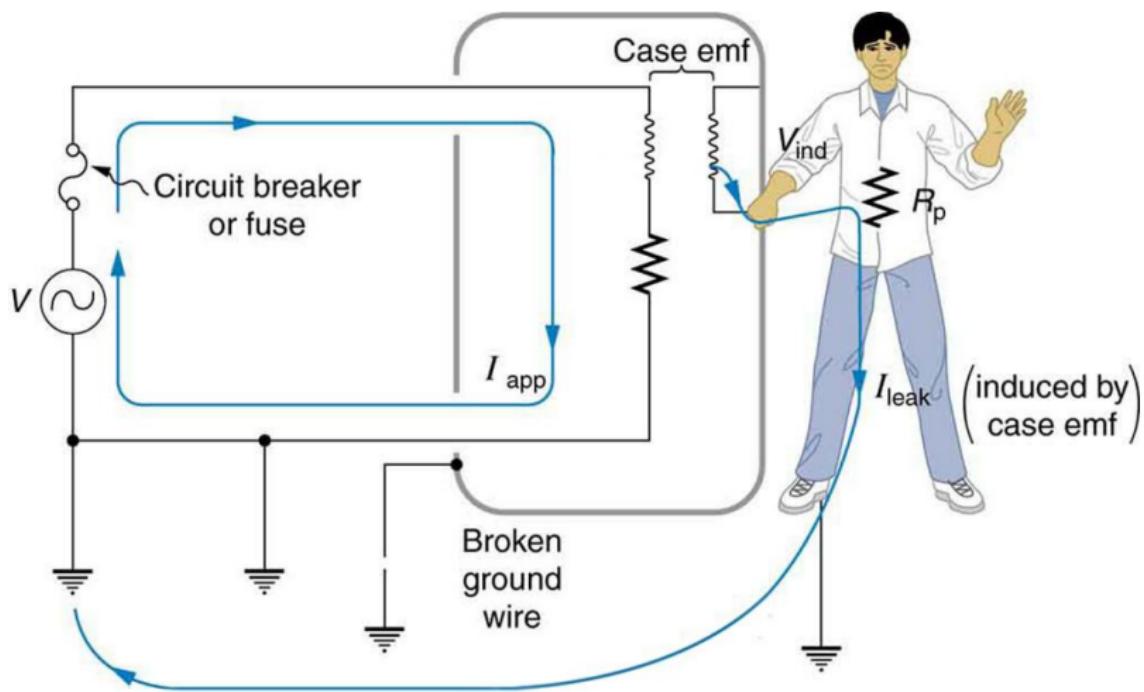


Electrical Safety - Three Wires



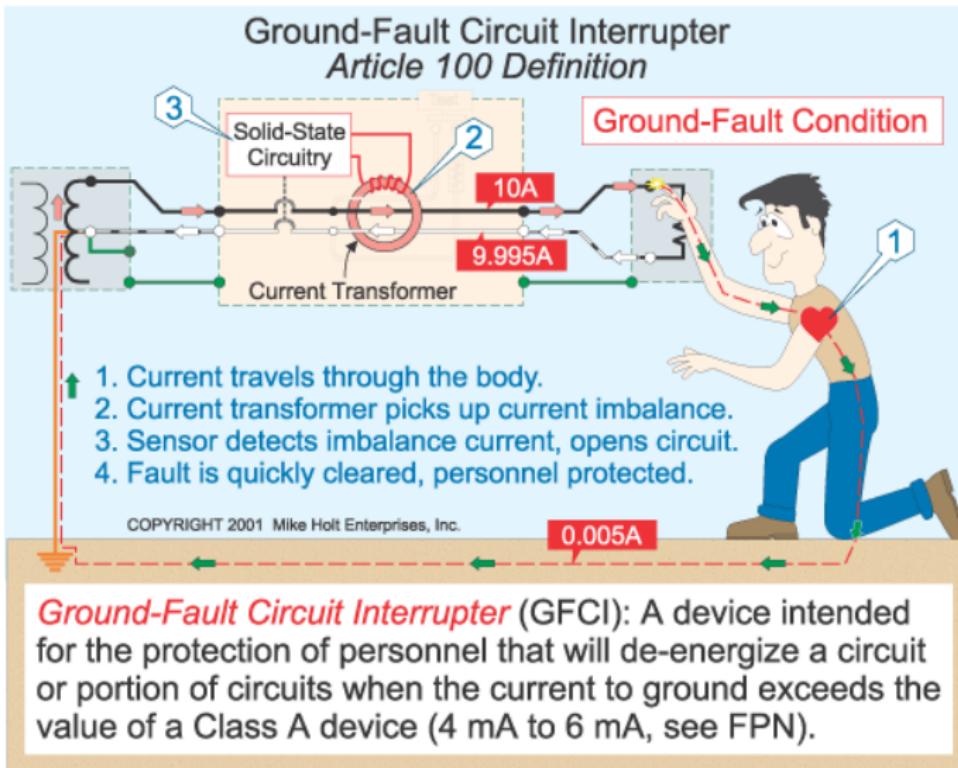


Electrical Safety - Electric Shock





Electrical Safety - GFCI

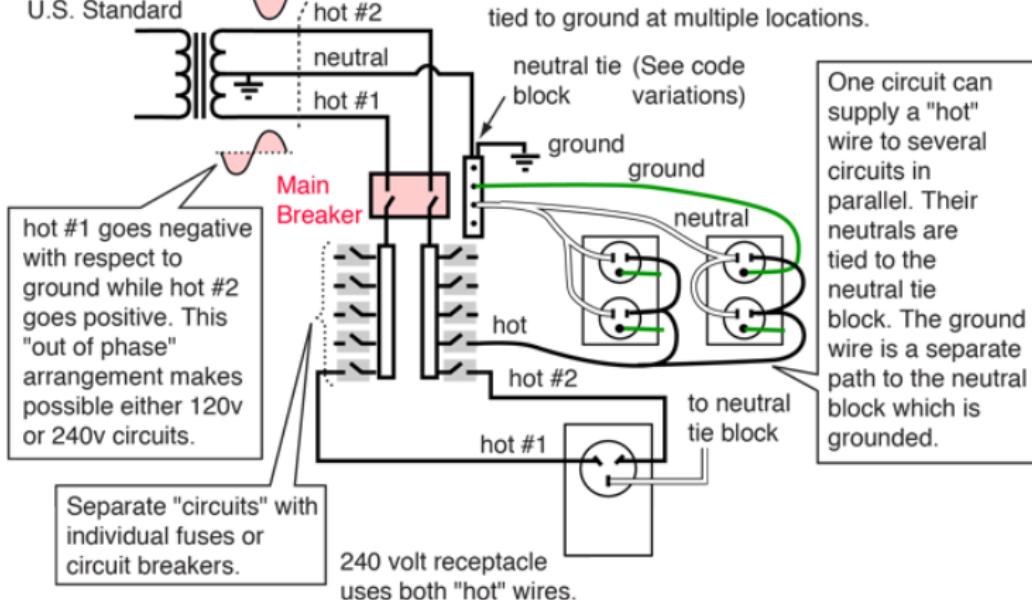




Electrical Safety - 240V

120 volts rms
60 Hz is the
U.S. Standard

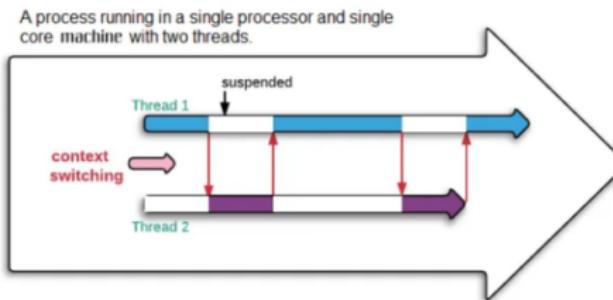
Three wires to house: two high voltage or "hot" wires
and a "neutral" return wire which is
tied to ground at multiple locations.





Threads

Threads allow concurrent execution of multiple bits of code.



Threads are an advanced programming feature and very powerful when used correctly. Used incorrectly they can introduce new and novel issues into your code that are often more difficult to debug than single-threaded code



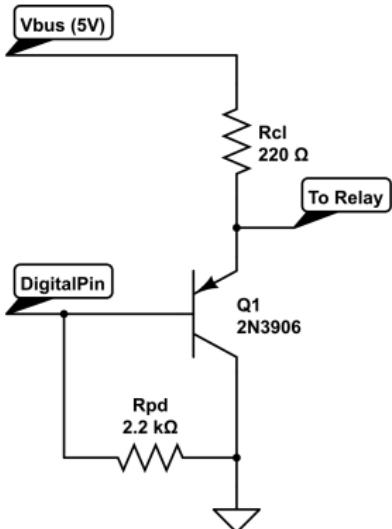
Threaded Dust Sensor

```
1 float concentration;           // Global varialbe to store concentration
2 void getConc();                // Declare thread function
3 SYSTEM_THREAD(ENABLED);        // Enable threading
4
5 void setup() {
6     Serial.begin(9600);
7     new Thread("concThread", getConc); // Initiate thread
8 }
9 void loop() {
10    if ((millis()-lastTime) > updateTime) {
11        Serial.printf("Time: %0.2f, CONC: %0.2f\n",millis()/1000.0,concentration);
12        lastTime = millis();
13    }
14 }
15 void getConc() {                           // The thread
16     const int sampleTime = 30000;
17     unsigned int duration, startTime;
18     startTime = 0;
19     lowpulseoccupancy=0;
20     while(true) {                         // Run the below loop forever
21         duration = pulseIn(DUSTPIN, LOW);
22         lowpulseoccupancy = lowpulseoccupancy+duration;
23         if ((millis()-startTime) > sampleTime) {
24             ratio = lowpulseoccupancy/(sampleTime*10.0);
25             concentration = 1.1*pow(ratio ,3)-3.8*pow(ratio ,2)+520*ratio+0.62;
26             startTime = millis();
27             lowpulseoccupancy=0;
28         }
29     }
30 }
```



Smart Houseplant Watering System

Design



2N3906 Emitter Follower

① Components:

- 2N3906 Emitter Follower and Relay
- BME280 and SEEED sensors
- OLED Display

② Publish soil moisture and room environmental data to a new dashboard.

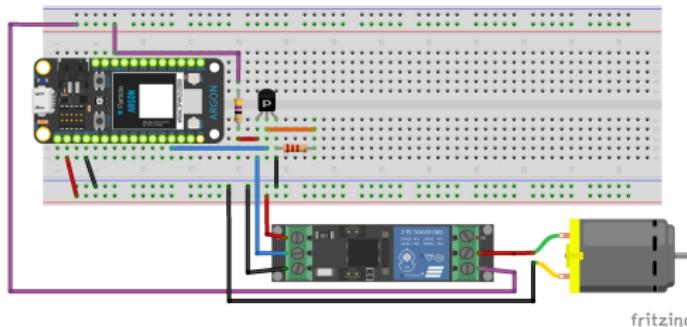
③ Automatically water your plant when the soil is too dry.

- Only turn on the pump for a very short period of time ($\frac{1}{2}$ sec).

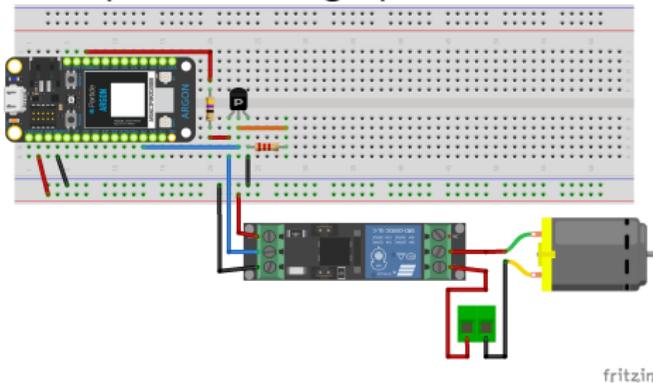
④ Integrate a button into your dashboard that manually waters the plant.



Relay and Pump Fritzing Diagram



If V_{BUS} doesn't provide enough power, add external supply.





Online Integrations Using Zapier



Zapier is an online automation tool that connects your favorite apps, such as Outlook, Slack, Mailchimp, and more. You can connect two or more apps to automate repetitive tasks.



Zapier Example

The Zapier logo, featuring the word "zapier" in a lowercase, sans-serif font. The letter "i" has a small orange asterisk (*) as its dot. The "z" is larger than the other letters.

```
Adafruit_MQTT_Subscribe *subscription;
while ((subscription = mqtt.readSubscription(10000))) {
    if (subscription == &gotmail) {
        Serial.printf("You Got Mail\n");
        digitalWrite(D7, HIGH);
        flagServo.write(90);
        delay[1000];
        digitalWrite(D7, LOW);
        flagServo.write(5);
    }
}
```

- ➊ Create an Zapier account using your cnm.edu email and sign up for the 14-day "Professional" trial.
- ➋ There are two Zapier examples in class_materials/ReferenceDocs:
 - Adafruit feed to email
 - Incoming email indicator to your Photon2
- ➌ Add to your Midterm project to send yourself an email whenever your soil is too dry.
In Zapier:
 - Create Feed Trigger from Adafruit
 - Add an Zapier filter
 - Add a Send to Email



Midterm 2 - Github

Create a new repository

Under Security, change visibility to Public

Danger Zone

Change repository visibility
This repository is currently internal. [Change visibility](#)

Transfer ownership
Transfer this repository to another user or to an organization where you have the ability to create repositories. [Transfer](#)

Archive this repository
Mark this repository as archived and read-only. [Archive this repository](#)

Delete this repository
Once you delete a repository, there is no going back. Please be certain. [Delete this repository](#)

IMPORTANT: Do not forget to add in the .gitignore file

- Must include credentials.h and \target
- Copy from any of the lessons



Adding video to hackster.io story

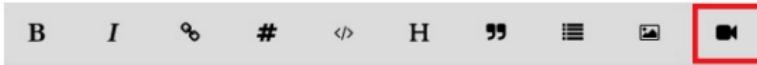
How do I add a video to my project?



Written by Benjamin Larralde
Updated over 2 years ago

To add a video, please upload it to Youtube or Vimeo first. You can leave it as unlisted if you prefer for it not to be accessible on those platforms.

Once the video is uploaded and you have a link for it, paste it in the story editor and press enter to embed it. Alternatively you can use the video button from the story editor toolbar:



Just make sure the cursor is placed where you want the video to be added first!



Midterm 2 Expectations

- ① Complete the Project Plan template from Brightspace and review with Instructors.
- ② Integrate the entire system
 - Create a user friendly Adafruit.io dashboard
 - Buy and/or create a structure to hold the plant (in your IoT flowerpot), pump, and sensors.
 - Integration of SMS/email messaging using Zapier.
 - Video demo your Plant Watering System
- ③ Add to your portfolio
 - Add the project to your Hackster.io feed.
 - Create a Github repository (with descriptive README.md file) to use throughout this project.
 - Don't forget the .gitignore.
- ④ Class presentation - hackster, video demo, dashboard

Module 12 - Memory: Bit, Bytes, and More



Setting Up Second Photon 2

In order for you to take home your intact plant watering system, it is time to setup our second Photon 2:

- ① Connect to WiFi
 - From VSCode: run L09_00_HelloReset
 - Or, use <https://docs.particle.io/tools/developer-tools/configure-wi-fi/>
- ② Get your device's serial number using

```
1 particle serial identify
2
3 Your device id is e00fce681fffffffffc08949b
4 Your system firmware version is 5.8.2
```

- ③ Claim the device to your account. Then, rename it to the name of your choice. This can only be done if it's breathing cyan.

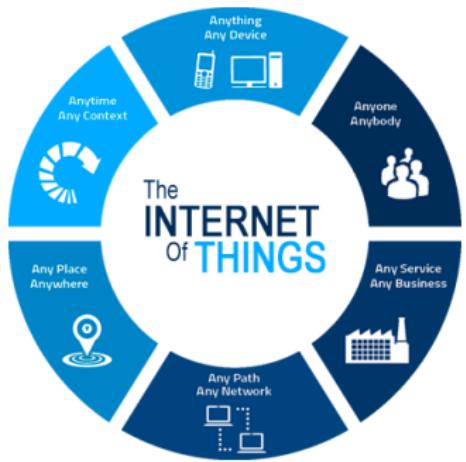
```
1 particle device add e00fce681fffffffffc08949b
2 particle device rename e00fce681fffffffffc08949b deviceName
```

NOTE:

- Replace e00fce681fffffffffc08949b with the serial number of your device
- Replace deviceName with a name of your choosing



Module 12 Objectives



- Learning Objectives

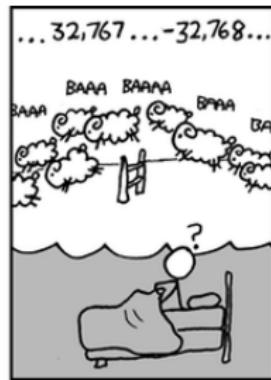
- 1 Negative Numbers
- 2 Bitwise Operations
- 3 EEPROM
- 4 Pointers

- Additional Items

- 1 3D Modeling Lesson 6 - Pin Wheels and Water Wheels
- 2 Quiz 8



Counting Sheep





Negative Numbers

Question: How are negative numbers represented in binary?

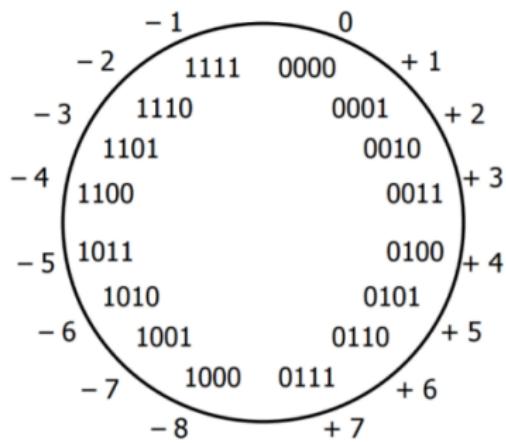
Type	Storage size	Value range
char	1 byte	-128 to 127 or 0 to 255
unsigned char	1 byte	0 to 255
signed char	1 byte	-128 to 127
int	2 or 4 bytes	-32,768 to 32,767 or -2,147,483,648 to 2,147,483,647
unsigned int	2 or 4 bytes	0 to 65,535 or 0 to 4,294,967,295
short	2 bytes	-32,768 to 32,767
unsigned short	2 bytes	0 to 65,535
long	4 bytes	-2,147,483,648 to 2,147,483,647
unsigned long	4 bytes	0 to 4,294,967,295

Answer: Left-most bit is 1 to signify negative. But wait...



2's Compliment

2's compliment is used as it makes the math consistent.



Integer		2's Complement
Signed	Unsigned	
5	5	0000 0101
4	4	0000 0100
3	3	0000 0011
2	2	0000 0010
1	1	0000 0001
0	0	0000 0000
-1	255	1111 1111
-2	254	1111 1110
-3	253	1111 1101
-4	252	1111 1100
-5	251	1111 1011

The negative plus the positive equals zero.



Bitwise Operations

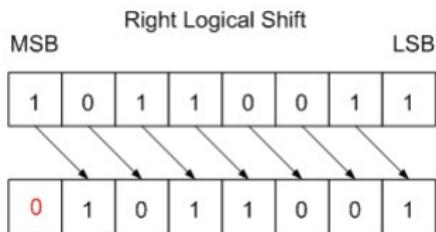
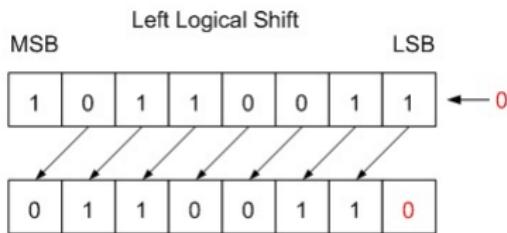
The following table lists the Bitwise operators supported by C. Assume variable 'A' holds 60 and variable 'B' holds 13, then –

Operator	Description	Example
&	Binary AND Operator copies a bit to the result if it exists in both operands.	$(A \& B) = 12$, i.e., 0000 1100
	Binary OR Operator copies a bit if it exists in either operand.	$(A B) = 61$, i.e., 0011 1101
^	Binary XOR Operator copies the bit if it is set in one operand but not both.	$(A ^ B) = 49$, i.e., 0011 0001
~	Binary One's Complement Operator is unary and has the effect of 'flipping' bits.	$(\sim A) = \sim(60)$, i.e., 1100 0011
<<	Binary Left Shift Operator. The left operand's value is moved left by the number of bits specified by the right operand.	$A << 2 = 240$ i.e., 1111 0000
>>	Binary Right Shift Operator. The left operand's value is moved right by the number of bits specified by the right operand.	$A >> 2 = 15$ i.e., 0000 1111

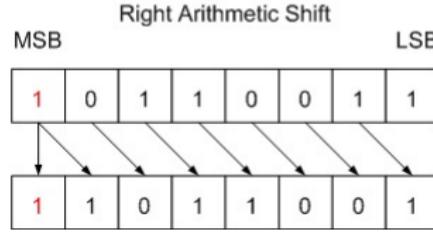
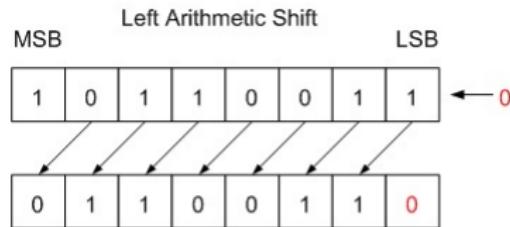


Bit Shifting

Logical Bit Shift (Unsigned Int)



Arithmetic Bit Shift (Int)



Whether the logical or arithmetic right shift is used depends on the datatype of the variable (unsigned or signed).



Combining Bit-wise Operations

Find value of the 3rd bit of 1110

- Right shift 1110 over 2 bits

$$1110 > 2 = 0011$$

- Select the rightmost bit with AND

$$0011 \& 0001 = 0001$$

- Putting it all together
 $(1110 > 2) \& 0001 = 0001$

Replace 3rd bit of 1001 with a 1

- Shift a 1 two bits to the left

$$0001 < 2 = 0100$$

- Replace the existing 3rd with OR

$$1001|0100 = 1101$$

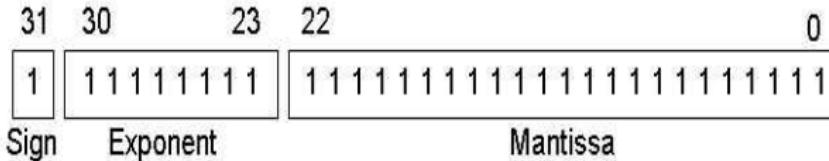
- Putting it all together
 $(0001 < 2)|1001 = 1101$

How is this applied to bytes, both in binary and then hex?



BONUS: But what about Floating Point

IEEE-754 Floating Point



Example: In scientific notation: $-36382.36 = -3.638236 * 10^4$

With binary exponential equals $-1 * 1.1103014945983887 * 2^{15}$

- Sign: Negative = 1
- Exponent: 15 = 10001110 (with an exponent bias of 10000000)
- Mantissa: 11103014945983887 = 00011100001111001011100

Floating point representation is: 11000111000011100001111001011100

In printf() if %i is used instead of a %f: -955,376,036



Types of Non-Volatile Memory

ROM	Read Only Memory - the data/code is defined by the circuits created during manufacturing. Used when the code/data never needs to be changed.	
PROM	Programmable Read Only Memory - an array of fuses that can be "blown" to embed code/data. Program once, read many.	 Fig. 3.71 Four-type PROM
EPROM	Erasable Read Only Memory - programmable array that can be erased by exposing to UV light and then reprogrammed. The window in the packaging allows the UV to reach the EPROM circuits. Chip needs to be removed from device and placed in special UV oven to erase and then placed on the programmer.	
EEPROM	Electrically Erasable Read Only Memory - an EEPROM that can be electrically erased and reprogrammed without being removed. Computer BIOS (basic input output system), cell phone memory, USB stick	



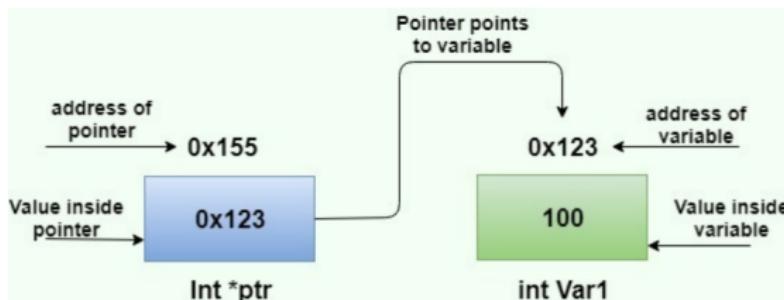
Electrically Erasable Programmable Read Only Memory

EEPROM emulation allows small amounts of data to be stored and persisted even across reset, power down, and user and system firmware flash operations. Since the data is spread across a large number of flash sectors, flash erase-write cycle limits should not be an issue in general.

```
1 len = EEPROM.length(); //available EEPROM bytes
2 // Photon2s have 4096 bytes of emulated EEPROM.
3 // Addresses 0x0000 through 0xFFFF
4
5 addr = 0x00AE;      //addr between 0 and len-1
6
7 val = 0x45;
8 EEPROM.write(addr, val);
9
10 value = EEPROM.read(addr);
```



Pointers



- ① A pointer is a variable whose value is the address of another variable.
- ② When you declare a pointer, the `*` symbol denotes that this variable is a pointer variable. For example:
 - Pointer to an Integer: `int *ptr;`
- ③ Reference operator (`&`) gives the address of a variable.
- ④ To get the value stored in the memory address, we use the dereference operator (`*`).



Pointers

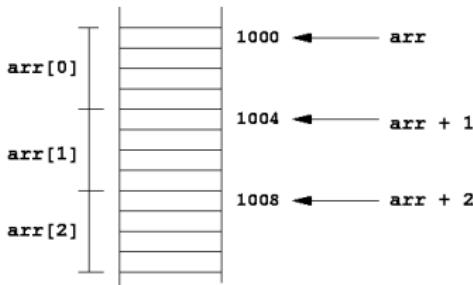
```
1 int data = 13;
2 int data2;
3 int *ptr;
4
5 void setup() {
6   Serial.begin(9600);
7   delay(1000);
8   ptr = &data;           //point ptr to the memory location of data
9   data2 = *ptr;          //set data2 to value of data (13)
10
11 // Print the Value and Address of the Variables
12 Serial.printf("Variable      Value      Address \n");
13 Serial.printf("  data        %i        0x%X  \n",data, &data);
14 Serial.printf("  ptr         0x%X        0x%X  \n",ptr, &ptr);
15 Serial.printf("  data2       %i        0x%X  \n",data2,&data2);
16 }
```

Serial monitor opened successfully:

Variable	Value	Address
data	13	0x2003E380
ptr	0x2003E380	0x2003E3F4
data2	13	0x2003E3F0



Pointers and Arrays



```
1 int arr[] = {100, 200, 300};  
2  
3 void loop() {  
4     // Compiler converts below to *(arr + 2).  
5     Serial.printf("%i \n", arr[2]);  
6  
7     // So below also works.  
8     Serial.printf("%i \n", *(arr + 2));  
9 }
```

When an array (`arr[]`) is declared, the variable is a pointer to the first element of a continuous block of memory. In this case there are 3 elements, each 4-bytes in size, for a total of 12-bytes.



Finding Average of an Array

```
1 // This function finds the average of an array.  
2 // The array is passed to it as a pointer.  
3  
4 float getAverage(int *array ,int size) {  
5     int j;  
6     float total=0;  
7     for(j=0;j<size;j++) {  
8         total += array[j];  
9     }  
10    return total/size;  
11 }
```



Finding Average of Arrays in Action

```
1 int xArray[4], yArray[256];
2 int *pointerX, *pointerY;
3 float average;
4 int i, sizeX, sizeY;
5
6 void setup() {
7     pointerX=&xArray[0];
8     sizeX=sizeof(xArray)/4;
9     pointerY=&yArray[0];
10    sizeY=sizeof(yArray)/4;
11    for(i=0;i<sizeX;i++) {
12        xArray[i] = random(0,255);
13    }
14    for(i=0;i<sizeY;i++) {
15        yArray[i] = random(256,512);
16    }
17    average = getAverage(pointerX, sizeX);
18    average = getAverage(pointerY, sizeY);
19 }
```

```
Array X Average = 162.50
Array Y Average = 388.35
xArray[0] value: 173, *pointerX: 173, pointerX: 0x2003E3DC
xArray[1] value: 179, *(pointerX+1): 179, pointerX+1: 0x2003E3E0
xArray[2] value: 110, *(pointerX+2): 110, pointerX+2: 0x2003E3E4
xArray[3] value: 188, *(pointerX+3): 188, pointerX+3: 0x2003E3E8
```



Returning Multiple Values from a Function

Arguments can be passed to a function by reference; thus, allowing multiple parameters to be returned by a function.

```
1 const int BILLBUTTON = D4;
2 float table1, table2; // subtotal for each table
3 float tax1, tax2, tip1, tip2;
4 bool billReady;
5
6 void calcBill(float subtotal, float *tax, float *suggestedTip);
7
8 void setup() {
9     // NOT SHOWN: Setup of Serial Monitor, pinMode, etc.
10    table1 = 23.76;
11    table2 = 47.29;
12 }
13
14 void loop() {
15     billReady = digitalRead(BILLBUTTON);
16     if(billReady) {
17         calcBill(table1,&tax1,&tip1); // pass by reference, memory address sent to function
18         calcBill(table2,&tax2,&tip2); // the function uses pointers to place values in memory
19         Serial.printf("Table1\nSubtotal:%0.2f\nTax:%0.2f\nSuggested Tip:%0.2f\n",table1,tax1,
20                     tip1);
21     }
22 }
23
24 void calcBill(float subtotal, float *tax, float *suggestedTip) {
25     *tax = subtotal * 0.07;
26     *suggestedTip = subtotal * 0.18;
27 }
```



Variables and Pointers - Values and Addresses

```

1 int x,y,sum,diff;
2 void addSubtract(int firstNum, int secondNum, int *theSum, int *theDiff);
3
4 void setup() {
5     x = 7;
6     y = 2;
7     addSubtract(x,y,&sum,&diff);
8 }
9
10 void loop() {}
11
12 void addSubtract(int firstNum, int secondNum, int *theSum, int *theDiff) {
13
14     *theSum = firstNum + secondNum;
15     *theDiff = firstNum - secondNum;
16 }
```

Before Function Call
x = 7, &x = 1007AE9C
y = 2, &y = 1007AEA0
sum = 0, &sum = 1007AE98
diff = 0, &diff = 1007AE94

At end of function
firstNum = 7, &firstNum = 10011DDC
secondNum = 2, &secondNum = 10011DD8
*theSum = 1007AE98, &theSum = 10011DD4
*theDiff = 1007AE94, &theDiff = 10011DD0

After Function Call
x = 7, &x = 1007AE9C
y = 2, &y = 1007AEA0
sum = 9, &sum = 1007AE98
diff = 5, &diff = 1007AE94



memcpy(), (char *), and strtol()

```
1 int color;
2 byte data[] = {0x23,0x42,0x41,0x34,0x32,0x35,0x44,0x39,0x35};
3 byte buf[6];
4
5
6 /* memcpy() - copy from specific memory locations to new locations
7 *   memcpy(to, from, size);
8 *       to -> pointer to starting address of where to copy to
9 *       from -> pointer to starting address of where to copy from
10 *      size -> number of btyes to copy
11 */
12
13 memcpy(buf, &data[1],6);      //copy bytes 1 through 6 and place in buf
14
15 /* (char *) - typecasting a data type to a char-type pointer */
16
17 Serial.printf("Converting the data array to ascii symbols returns %s,\n",(char *)data);
18
19
20 /* strtol() - string to long - similar to atoi()
21 *   strtol(charString, end, base)
22 *       charString -> string that contains number to be converted
23 *       end -> character to end conversion on (set to NULL)
24 *       base -> base of integer (16 for hex)
25 */
26
27 color = strtol((char *)buf,NULL,16); // convert string to int (hex)
```



EXAMPLE: Adafruit MQTT Subscribe - Color Picker

Pick a Color



#fa7802

July 14th 2021, 11:23:46AM

Color Data

```
2021/07/14 10:35AM Default ColorSend #1d31e5
2021/07/14 10:36AM Default ColorSend #e51d3f
2021/07/14 11:19AM Default ColorSend #3fe51d
2021/07/14 11:19AM Default ColorSend #3a1de5
2021/07/14 11:20AM Default ColorSend #b826fb
2021/07/14 11:22AM Default ColorSend #f3fb26
2021/07/14 11:23AM Default ColorSend #fa7802
```

```
1 int color;
2 byte buf[6];
3
4 Adafruit_MQTT_Subscribe *subscription;
5 while ((subscription = mqtt.readSubscription(1000))) {
6     if (subscription == &mqttColor) {
7         Serial.printf("Received from Adafruit: %s \n", (char *)mqttColor.lastread);
8         memcpy(buf, &mqttColor.lastread[1], 6);           //strip off the '#'
9         Serial.printf("Buffer: %s \n", (char *)buf);
10        color = strtol((char *)buf, NULL, 16);           // convert string to int (hex)
11        Serial.printf("Buffer: 0x%02X \n", color);
12    }
13 }
```



L12_Memory Assignments



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

① L12_01_ColorPicker

- Create a feed and dashboard on Adafruit.io using the Color Picker block.
- Subscribe to your Color Picker feed and convert the lastRead() to a integer (hex)
- Light up your NeoPixel ring the received color.
- Using pointers create a function to convert the hex color into individual R,G,B components using Bit Shifting and AND.
- From void loop, store the components of the color as bytes in the Particle's EEPROM.

② L12_02_RetrieveShow

- Set pixel ring to white for at least 1 second
- Retrieve the color from EEPROM memory.
- Convert to a hex color code (e.g. 0xABCDFF)
- Display the color on the NeoPixel ring using setPixelColor(n,hexColor)



Useful Properties: Identity Element

An identity element is a special type of element of a set with respect to a binary operation on that set, which leaves any element of the set unchanged when combined with it.

Addition:

$$x + 0 = x \quad (1)$$

Multiplication:

$$x * 1 = x \quad (2)$$

Bitwise AND:

$$x \& 1 = x \quad (3)$$

Bitwise OR:

$$x | 0 = x \quad (4)$$



Bonus: Passing Objects via Reference

```
1 // Declare Objects
2 Adafruit_NeoPixel pixel(30, SPI1, WS2812B);
3
4 // Declare pixelFill function with passing in neopixel object by reference
5 void pixelFill(Adafruit_NeoPixel *strip, int start, int end, int pixColor);
6
7 SYSTEM_MODE(SEMI_AUTOMATIC);
8
9 void setup() {
10     pixel.begin();
11 }
12
13 void loop() {
14     pixelFill(&pixel, 0, 30, 0x0000FF); // note the pass by reference "&pixel"
15 }
16
17 // Light up a segment of pixels
18 void pixelFill(Adafruit_NeoPixel *strip, int start, int end, int pixColor) {
19     int i;
20
21     for(i=start;i<=end;i++) {
22         strip->setPixelColor(i,pixColor); //note the "->" instead of the "."
23     }
24     strip->show();
25 }
```

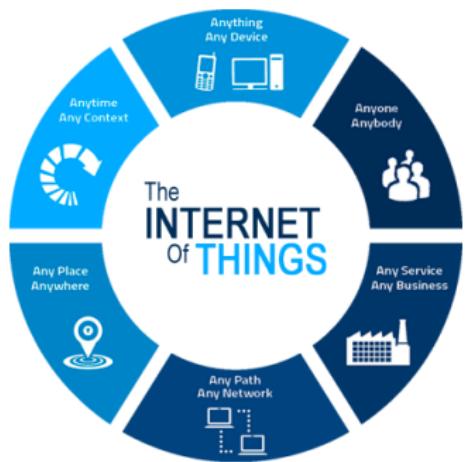


Added Bonus: Array of Functions via Pointers

```
1 //Array of pointers to each of the functions
2 int (* funky[4])(int x, int y) = {add,sub,mult,divi};
3
4 int a,b,answer,i;
5
6 void setup() {
7     Serial.begin(9600);
8 }
9
10 void loop() {
11     a = random(0,100);
12     b = random(0,100);
13     for(i=0;i<4;i++) {
14         answer = funky[i](a,b);
15         Serial.printf("For function %i: a = %i and b = %i equals %i \n",i,a,b,answer);
16         delay(250);
17     }
18     Serial.printf("\n\n\n");
19     delay(3000);
20 }
21
22 // The Functions
23 int add(int x,int y) {return x+y;}
24
25 int sub(int x,int y) {return x-y;}
26
27 int mult(int x,int y) {return x*y;}
28
29 int divi(int x,int y) {return x/y;}
```



Module 12 Review



- Learning Objectives

- 1 Negative Numbers
- 2 Bitwise Operations
- 3 EEPROM
- 4 Pointers

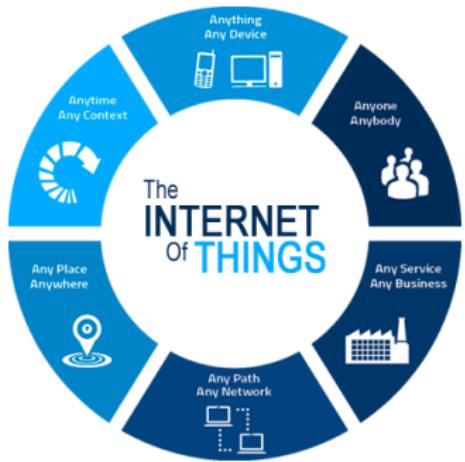
- Additional Items

- 1 3D Modeling Lesson 6 - Pin Wheels and Water Wheels
- 2 Quiz 8

Module 13 - Motion



Module 13 Objectives



- Learning Objectives

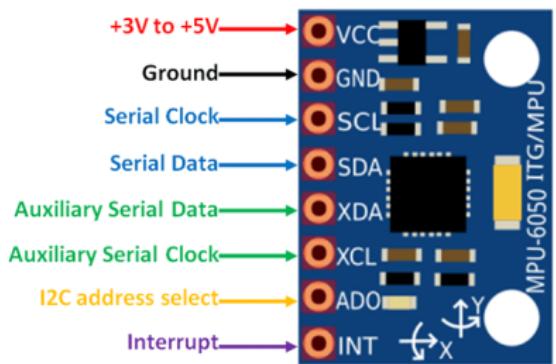
- ① Utilized a Data Sheet to learn to access a component
- ② Accelerometers and Gyroscopes
- ③ A little bit of trig and calculus
- ④ Stepper motors
- ⑤ Hall effect sensors
- ⑥ Interrupts

- Additional Items

- ① Quiz 9



MPU6050 Accelerometer

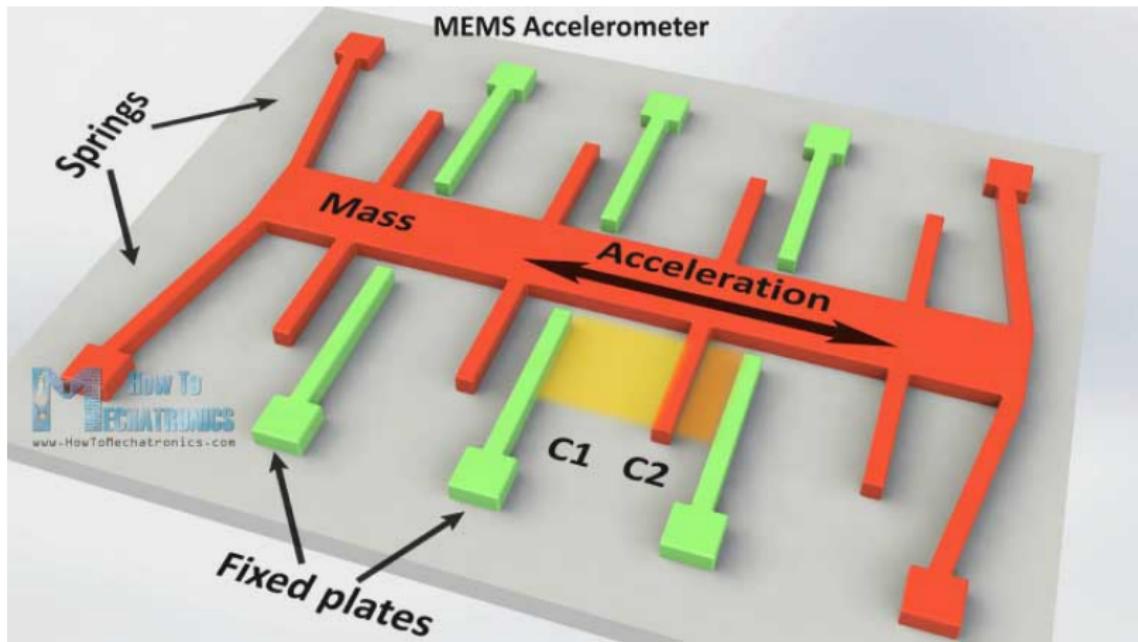


- Data Output: signed 16 Bit
- Accel range: $\pm 2 \pm 4 \pm 8 \pm 16g$
- Gyros range: $\pm 250 \ 500 \ 1000 \ 2000^{\circ}/s$

- XDA and XCL refer to the I2C bus that the MPU-6050 controls, so it can read from slave devices such as magnetometers etc.
- ADO pin changes I2C address when grounded.
- The interrupt pin notifies the MPU about available data. To reduce power consumption, the processor can go into sleep mode and the interrupt can be used to wake up the processor.



Accelerometers





DIP Switches and Register Maps



Remember: serial usb setup-done

Table 18: Memory map

Register Name	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Reset state
hum_lsb	0xFE				hum_lsb<7:0>					0x00
hum_msb	0xFD				hum_msb<7:0>					0x80
temp_xlsb	0xFC		temp_xlsb<7:4>			0	0	0	0	0x00
temp_lsb	0xFB				temp_lsb<7:0>					0x00
temp_msb	0xFA				temp_msb<7:0>					0x80
press_xlsb	0xF9		press_xlsb<7:4>			0	0	0	0	0x00
press_lsb	0xF8				press_lsb<7:0>					0x00
press_msb	0xF7				press_msb<7:0>					0x80
config	0xF5	t_sb[2:0]			filter[2:0]			spi3w_en[0]		0x00
ctrl_meas	0xF4	osrs_t[2:0]			osrs_p[2:0]		mode[1:0]			0x00
status	0xF3				measuring[0]			im_update[0]		0x00
ctrl_hum	0xF2						osrs_h[2:0]			0x00
calib26.calib41	0xE1..0xF0				calibration data					individual
reset	0xE0				reset[7:0]					0x00
id	0xD0				chip_id[7:0]					0x60
calib00..calib25	0x88..0xA1				calibration data					individual

Registers:	Reserved registers	Calibration data	Control registers	Data registers	Status registers	Chip ID	Reset
Type:	do not change	read only	read / write	read only	read only	read only	write only



REMINDER - Data Types: Numbers

Data Type	8-bit AVR systems (Arduino Uno)			32-bit ARM systems (Teensy 3.2)		
	bytes	range (signed)	range (unsigned)	bytes	range (signed)	range (unsigned)
char	1	-128 to 127	0 to 255	1	-128 to 127	0 to 255
short	2	+/- 32,767	0 to 65,353	2	+/- 32,767	0 to 65,353
int	2	+/- 32,767	0 to 65,353	4	+/- 2,147,483,648	0 - 4,294,967,295
long	4	+/- 2,147,483,648	0 - 4,294,967,295	4	+/- 2,147,483,648	0 - 4,294,967,295
long long	8	+/- 9,223,372,036,854,770,000	0 to 18,446,744,073,709,551,615	8	+/- 9,223,372,036,854,770,000	0 to 18,446,744,073,709,551,615
float	4	3.4E +/- 38 (7 digits)	n/a	4	3.4E +/- 38 (7 digits)	n/a
double	4	3.4E +/- 38 (7 digits)	n/a	8	1.7E +/- 308 (15 digits)	n/a
long double	8	1.7E +/- 308 (15 digits)	n/a	8	1.7E +/- 308 (15 digits)	n/a
Unambiguous						
uint8_t	1	n/a	0 to 255	1	n/a	0 to 255
int8_t	1	-128 to 127	n/a	1	-128 to 127	n/a
uint16_t	2	n/a	0 to 65,353	2	n/a	0 to 65,353
int16_t	2	+/- 32,767	n/a	2	+/- 32,767	n/a
uint32_t	4	n/a	0 - 4,294,967,295	4	n/a	0 - 4,294,967,295
int32_t	4	+/- 2,147,483,648	n/a	4	+/- 2,147,483,648	n/a

The MPU6050 provides acceleration as a signed 16-bit number. The data type int16_t should be used to ensure the sign-bit is in the correct location.



Initializing MPU6050

```
1 // Initialize the MPU in the void setup()
2 void setup() {
3     // Begin I2C communications
4     Wire.begin();
5
6     // Begin transmission to MPU-6050
7     // MPU_ADDR should be declared as a CONST INT
8     Wire.beginTransmission(MPU_ADDR);
9
10    // Select and write to PWR_MGMT1 register
11    Wire.write(0x6B);
12    Wire.write(0x00); // wakes up MPU-6050
13
14    // End transmission and close connection
15    Wire.endTransmission(true);
16 }
```



Reading Acceleration Data from the MPU-6050

```
1 // Declare variables
2 byte accel_x_h, accel_x_l;      //variables to store the individual bytes
3 int16_t accel_x;                //variable to store the x-acceleration
4
5 void loop() {
6     // Set the "pointer" to the 0x3B memory location of the MPU and wait for data
7     Wire.beginTransmission(MPU_ADDR);
8     Wire.write(0x3B); // starting with register 0x3B
9     Wire.endTransmission(false); // send the set pointer command and keep active.
10
11    // Request and then read 2 bytes
12    // Syntax:
13    //     Wire.requestFrom(I2C_addr, quantity, stop);
14    //     Wire.read(); //repeat this for each byte to be read
15
16    Wire.requestFrom(MPU_ADDR, 2, true);
17    accel_x_h = Wire.read(); // x accel MSB
18    accel_x_l = Wire.read(); // x accel LSB
19
20    accel_x = accel_x_h << 8 | accel_x_l;      // what happens if declared int instead?
21    Serial.printf("X-axis acceleration is %i \n",accel_x);
22 }
```

Note: the data is stored in Big Endian Byte Order. The most significant byte (the "big end") of the data is placed at the byte with the lowest address. The rest of the data is placed in the next byte.



Tale of Three Hexes

Hex values are used three different ways in our I^2C communications:

① I^2C Address

- `Wire.beginTransmission()`
- `Wire.endTransmission()`
- `Wire.requestFrom()`

② Set a pointer to a register (memory location)

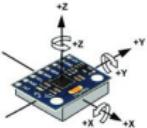
- The first `Wire.write()` after `Wire.beginTransmission`

③ As Data

- All subsequent `Wire.write()` after the first
- `Wire.read()`



Assignment: L13_Motion



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

① L13_01_MP6050

- Read values from the registers associated with X, Y, and Z acceleration.
- Convert the returned acceleration values to standard gravity units (e.g. when flat on the table, $a_z = -1G$).

② L13_02_AutoRotate

- Display date and time on an OLED display.
- Use accel values to auto-rotate the OLED.

③ Extra

- Modify L13_01_MP6050 to be able to modify range/sensitivity with a button or encoder.



SOH CAH TOA

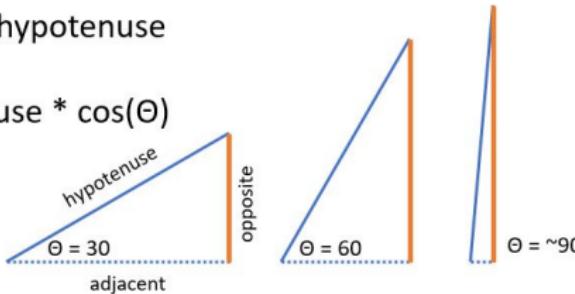
- $\sin = \text{opposite over hypotenuse}$
- $\cos = \text{adjacent over hypotenuse}$
- $\tan = \text{opposite over adjacent}$

$$\cos(\Theta) = \text{adjacent} / \text{hypotenuse}$$

or

$$\text{Adjacent} = \text{hypotenuse} * \cos(\Theta)$$

$$\Theta = 0$$



$$\sin(\Theta) = \text{opposite} / \text{hypotenuse}$$

or

$$\text{opposite} = \text{hypotenuse} * \sin(\Theta)$$



Scalars and Vectors

Scalars are quantities that are fully described by a magnitude (or numerical value) alone.

Vectors are quantities that are fully described by both a magnitude and a direction.

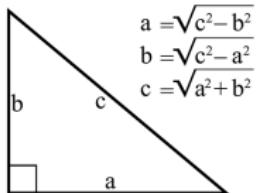
Scalar	Vector
 Volume	 Time
 Temperature	 Speed
 Weight	 Thrust
 Magnetic field	 Velocity



Pythagorean Theorem in 3 Dimensions

The Pythagorean Theorem

$$c^2 = a^2 + b^2$$



$$a = \sqrt{c^2 - b^2}$$

$$b = \sqrt{c^2 - a^2}$$

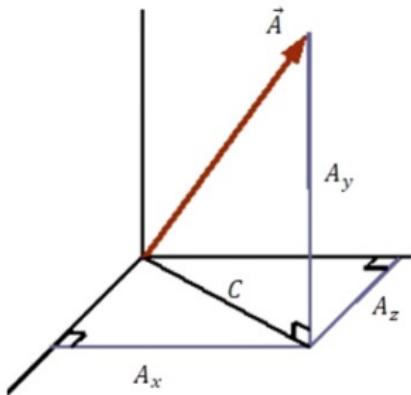
$$c = \sqrt{a^2 + b^2}$$

To add orthogonal (at right angles to each other) vectors in 3 Dimensions:

- $C = \sqrt{A_x^2 + A_y^2}$

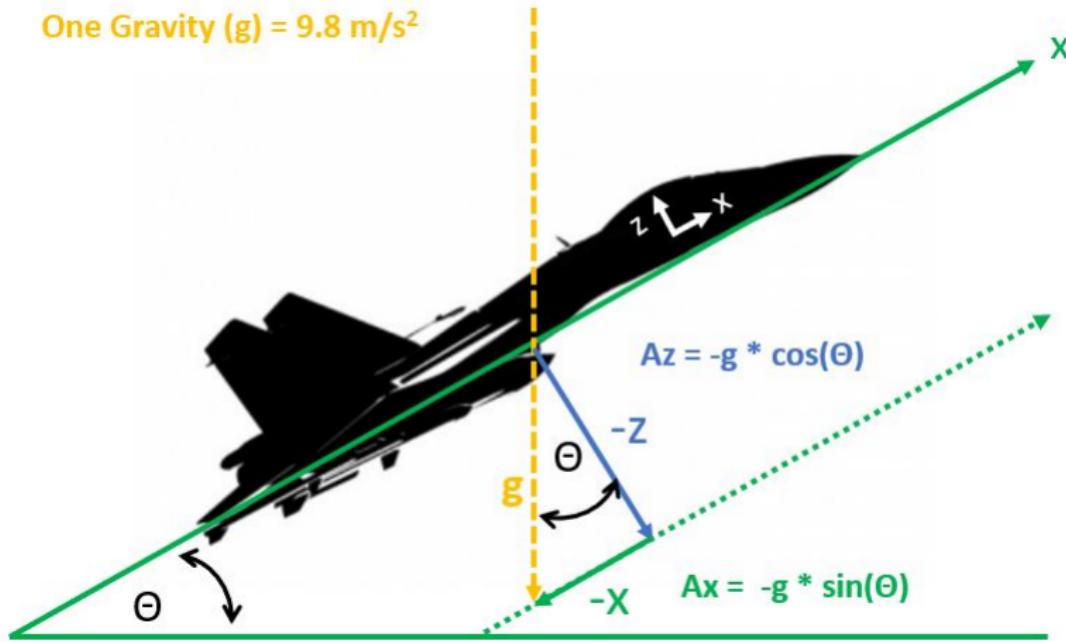
- $A_{total} = \sqrt{C^2 + A_z^2}$

- $A_{total} = \sqrt{A_x^2 + A_y^2 + A_z^2}$



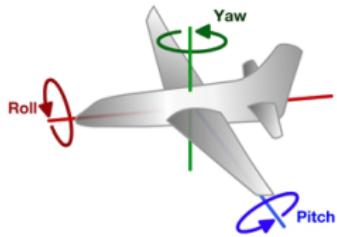


Gravity and Orientation





Assignment: L13_Motion



- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

For the below, recall that trigonometric functions return radians which needs to be converted to degrees. See the Unit Circle slide in L02_HelloLED.

① L13_03_Airplane

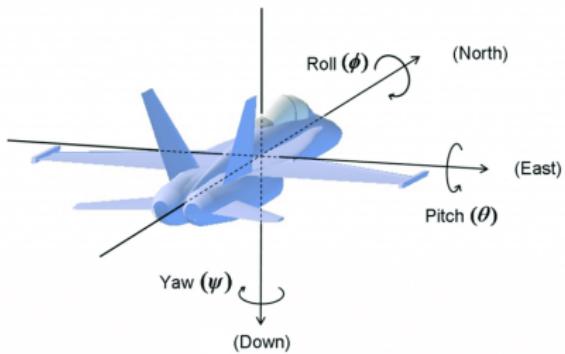
- Calculate pitch $\theta = -\text{asin}(a_x)$.
- Calculate roll $\phi = \text{atan2}(a_y, a_z)$.

② L13_04_Shock

- Store a_{tot} in an array every 10ms for 5s.
- Find and print the max value from the array.
- Repeat.
- Note: When at rest, the $a_{tot} \approx 1$.



Pitch and Roll Improved



$$\text{Pitch}(\Theta) = \arctan\left(\frac{a_x}{\sqrt{a_y^2+a_z^2}}\right)$$

$$\text{Roll } (\Phi) = \arctan\left(\frac{a_y}{\sqrt{a_x^2+a_z^2}}\right)$$

$$\text{Yaw } (\Psi) = \arctan\left(\frac{\sqrt{a_x^2+a_y^2}}{a_z}\right)$$



Assignment: L13_Motion (Extra Credit)



① Modify L13_03_Airplane

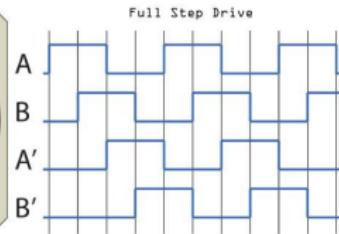
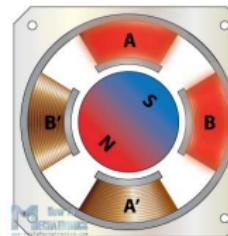
- Improve L13_03_Airplane with the more detailed trigonometric equations.
- Use the NeoPixel ring to visualize roll.
- When holding the accelerometer a fixed distance ($\approx 6\text{in}$) from the NeoPixel tower, change pitch and light up the pixel it is pointing at.
- Note: for the 3rd bullet use TOA from SOH-CAH-TOA



Stepper Motors

28BYJ Stepper Motor

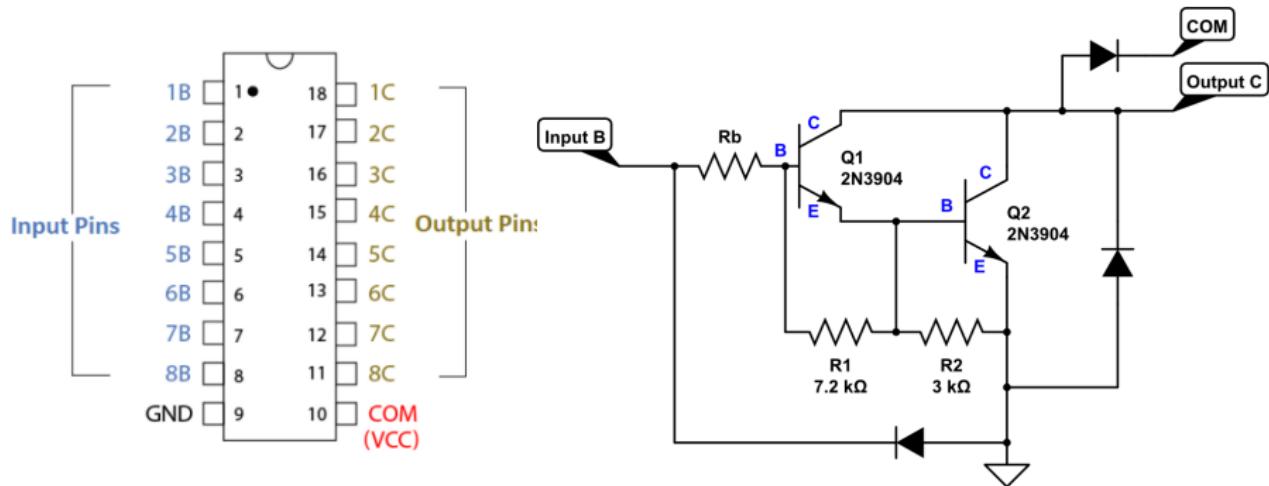
- 2048 steps per revolution
 - 32 steps per rotor revolution
 - Gear ratio 1:64
- Capable of 10-15 RPM (at 5V)
- ULN2003 Darlington Array



```
1 #include "Stepper.h" // Use the command palette to install the Stepper library
2
3 /* Stepper Object
4  SPR is the motors steps per rotation
5  IN1,IN2,IN3,IN4 are the pins connected to the motor control board's IN pins
6 */
7 Stepper myStepper(SPR,IN1,IN3,IN2,IN4);
8
9 void setup() {
10   myStepper.setSpeed(speed); // speed is an integer specifying RPM
11 }
12
13 void loop() {
14   myStepper.step(steps); // steps is a signed integer indicating how many steps to move
15 }
```



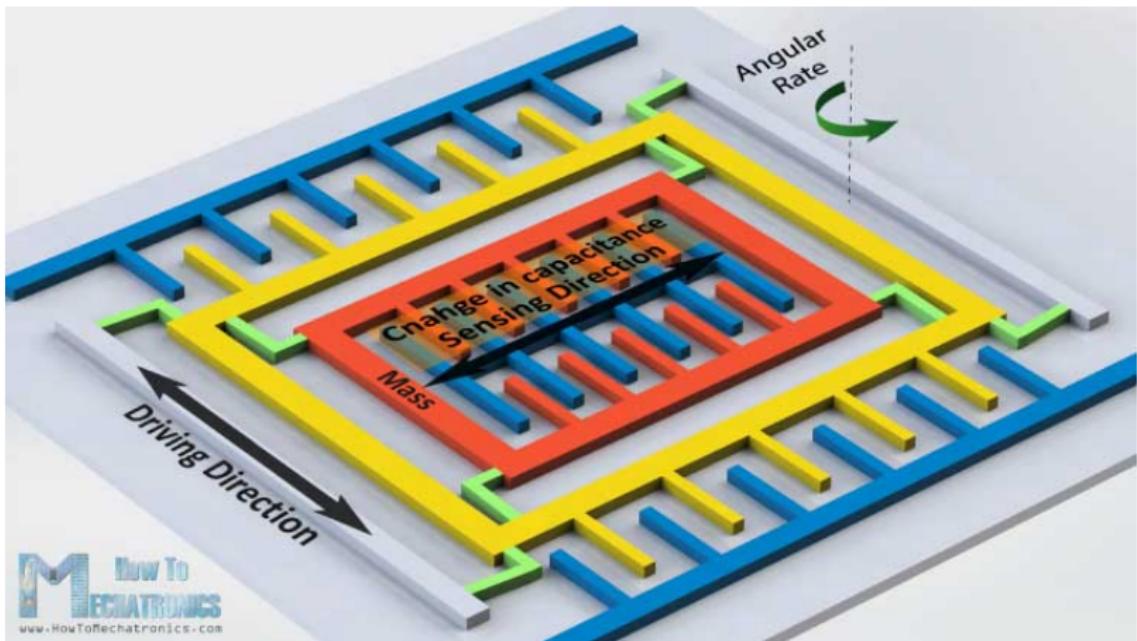
ULN2003 Darlington Array



A Darlington Array is a set of current amplifying circuits that take outputs from the microcontroller and boost the current used to drive the motor.



Gyroscopes

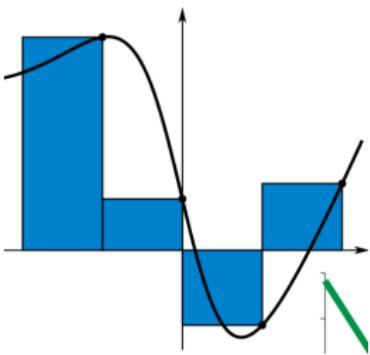


The gyroscope measures angular velocity (degrees per second).



Integration via Reimann Sum

The Riemann^a Sum can be used to find the "area under a curve":



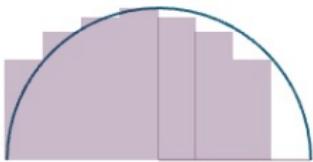
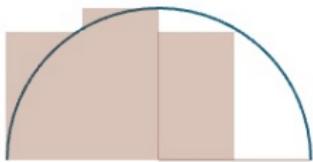
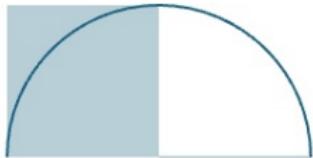
- Divide the curve into segments vertically
- Find the point where the curve meets the right side of the first segment
- Draw a horizontal line from that point to the left side of the segment
- Shade in the resulting rectangle
- Repeat for all segments
- Sum up the area of all the rectangles^b

^aGeorg Friedrich Bernhard Riemann was a German mathematician from the mid-1800's

^bThis is one of many ways to create the shaded area



Reimann Sum Example



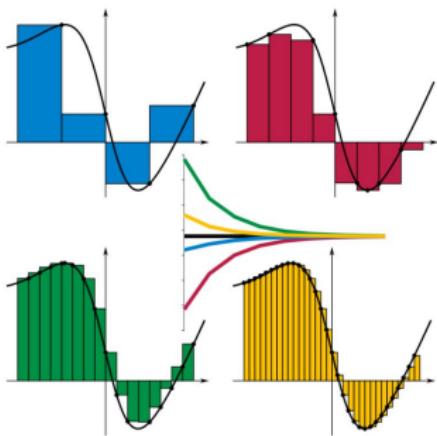
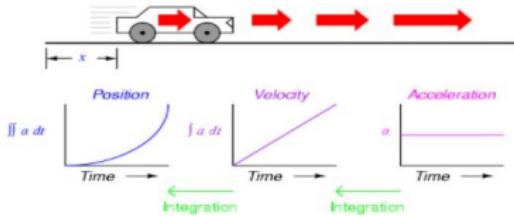
Take as an example, a half circle with a radius of 2 ($\text{area} = 2\pi = 6.28$). It can be divided into rectangular segments. Adding the areas approximates the area of the half circle.

The more segments, the more accurate:

- 2-segments: 4
- 4-segments: 5.46
- 8 segments: 5.99
- 16-segments: 6.18



Acceleration, Velocity, and Position



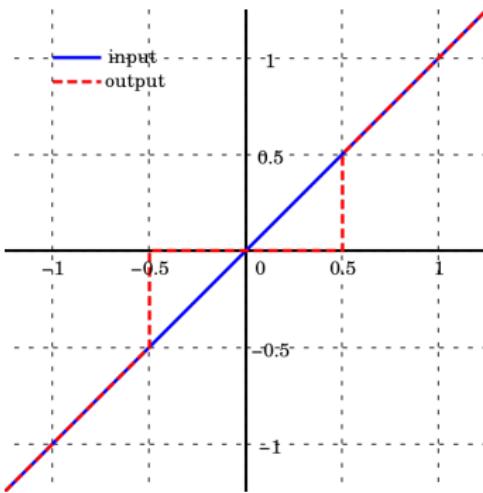
The Reimann Sum method can be used to "integrate" acceleration to velocity and velocity to position.

- Gyroscope output is angular velocity: ω ($\frac{\text{degrees}}{\text{second}}$)
- To get change in angular position ($\Delta\theta$), multiple each angular velocity by the time step: $\Delta\theta = \omega * \Delta t$
- Use the Reimann Sum to get the resulting angular position

$$\theta = \sum_{t=0}^{t=T} (\omega * \Delta t)$$



Deadband



A deadband is a band of input values that in a control system create an output that is zero.



Assignment: L13_Motion



- Notebook:
schematic
- Fritzing diagram
- Wire your circuit
- Write the code

① L13_05_DuckGoRound

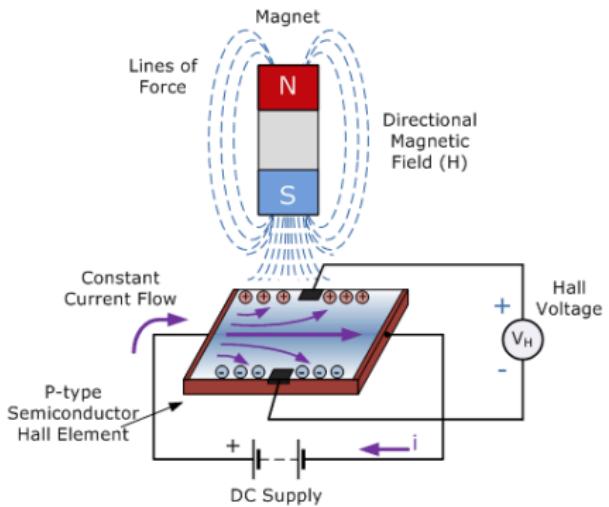
- Place your duck onto the stepper motor.
- Wire the stepper motor noting the order:
IN1, IN3, IN2, IN4.
- In void loop(), move the motor 2 rotations
clockwise, pause, 1 rotation
counter-clockwise, repeat.

② L13_06_DriveByWire

- Connect the MPU-6050 to your system.
- Obtain the z-axis rotation from the
appropriate register on the MPU-6050.
Convert to angular rotation ($^{\circ}$ per sec).
- Calculate the angular position ($^{\circ}$) of the
gyroscope.
- Have the stepper motor track movement in
the gyroscope.



Hall Effect Sensor



Discovered by Edwin Hall in 1879, the Hall Effect is the production of a voltage difference (the Hall voltage) across an electrical conductor, transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current.



Interrupts

Interrupts are a way to write code that is run when an external event occurs. As a general rule, interrupt code should be very fast, and non-blocking. This means performing transfers, such as I2C, Serial, TCP should not be done as part of the interrupt handler. Rather, the interrupt handler can set a variable which instructs the main loop that the event has occurred.

```
1 pinMode(pin, INPUT); \\ can also use INPUT_PULLUP or INPUT_PULLDOWN  
2 attachInterrupt(pin, function, mode);
```

Mode: defines when the interrupt should be triggered. Three constants are predefined as valid values:

- CHANGE to trigger the interrupt whenever the pin changes value,
- RISING to trigger when the pin value goes from low to high,
- FALLING for when the pin value goes from high to low.



Software Timers

There are also software timer interrupts. The Photon2 can manage up to 10 timers simultaneously.

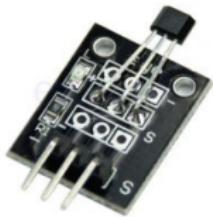
```
1 Timer timer(1000,printEverySecond);
2
3 void setup() {
4     Serial.begin(9600);
5     timer.start();
6 }
7
8 void printEverySecond() {
9     static int count = 0;
10    Serial.printf("count=%i, time = %u ms \n", count,millis());
11    count++;
12 }
```

Note:

- The timer callback is similar to an interrupt - it shouldn't block.
- Multiple timers are serviced sequentially when several timers trigger simultaneously, thus requiring special consideration when writing callback functions.



Assignment: L13_Motion



① L13_07_Alarm

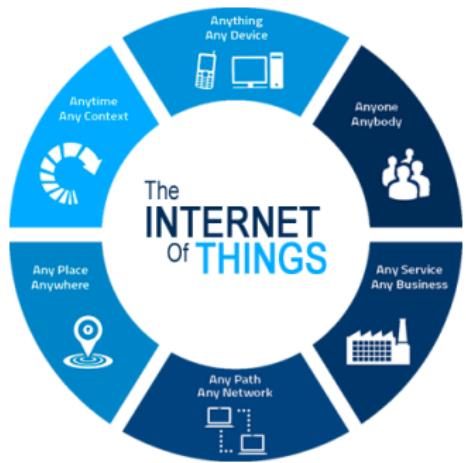
- Connect Hall Effect Sensor, button, and Neopixel to simulate an alarm system.
- Use the button to enable / disable alarm.
- Light up NeoPixels:
 - BLUE when alarm disarmed
 - GREEN when armed and magnet detected.
 - Blinking RED when armed and magnet is not detected.

② L13_08_RPM

- Notebook:
 - schematic
 - Fritzing diagram
 - Wire your circuit
 - Write the code
- Place magnet on shaft of a drill
 - Create an interrupt function that returns the time per rotation using the Hall Effect Sensor.
 - Convert this time to rotations per minute.
 - Display on Adafruit.io databoard.
 - EXTRA:
 - Create a speedometer using a servo motor.



Module 13 Review



- Learning Objectives

- ① Utilized a Data Sheet to learn to access a component
- ② Accelerometers and Gyroscopes
- ③ A little bit of trig and calculus
- ④ Stepper motors
- ⑤ Hall effect sensors
- ⑥ Interrupts

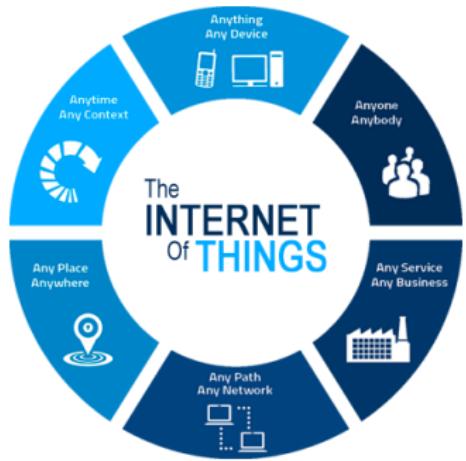
- Additional Items

- ① Quiz 9

Module 14 - Radio



Module 14 Objectives



- Learning Objectives

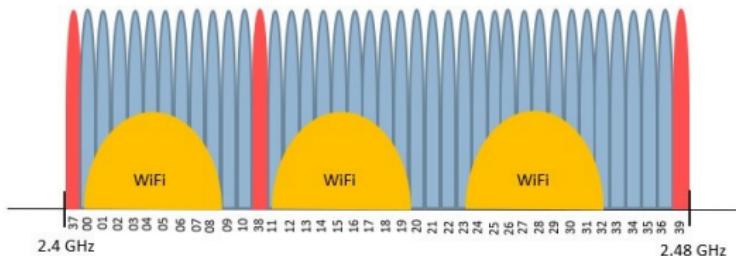
- 1 Bluetooth
- 2 GPS
- 3 UART / SPI
- 4 LoRa

- Additional Items

- 1 3D Modeling Lesson 6 - ESP32-CAM
- 2 Quiz 10



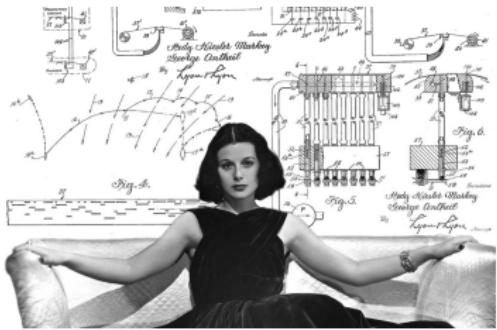
Bluetooth



- The Bluetooth protocol operates at 2.4GHz in the same unlicensed ISM frequency band where RF protocols like ZigBee and WiFi also exist.
- Bluetooth networks (commonly referred to as piconets) use a master/slave model to control when and where devices can send data. In this model, a single master device can be connected to up to seven different slave devices. Any slave device in the piconet can only be connected to a single master.



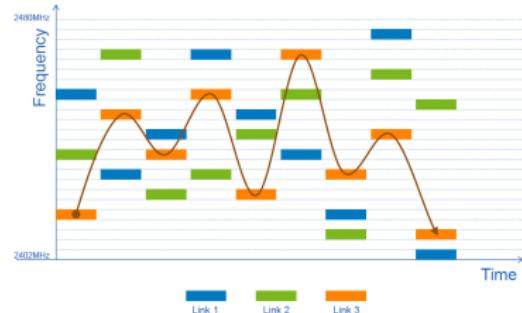
Frequency Hopping



Hedy Lamarr (actress/inventor)

- Starred in over 35 movies
- Invented Frequency Hopping^a
- "Mother of WiFi"

^awith composer George Antheil



Frequency Hopping

- Rapidly change frequencies
- Uses pseudo-random sequence
- Avoids interference



Bluetooth - Generic Access Profile

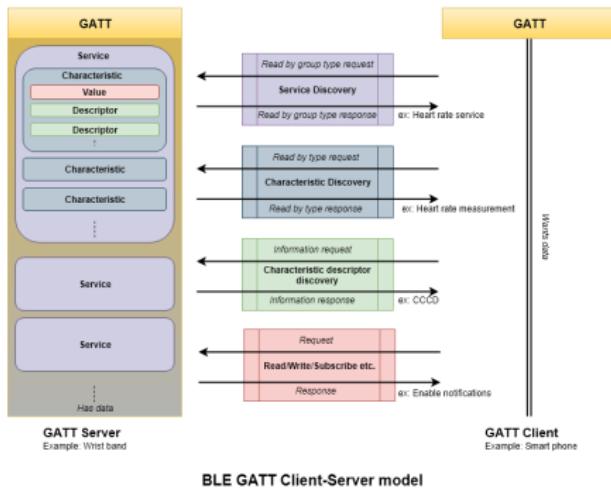


- The Generic Access Profile (GAP) controls connections and advertising in Bluetooth. GAP is what makes your device visible to the outside world, and determines how two devices can (or can't) interact with each other.
- GAP defines various roles for devices, but the two key concepts to keep in mind are Central devices and Peripheral devices.
 - Peripheral devices are small, low power, resource constrained devices that can connect to a much more powerful central device. Peripheral devices are things like a heart rate monitor, a BLE enabled proximity tag, etc.
 - Central devices are usually the mobile phone or tablet that you connect to with far more processing power and memory.



Bluetooth - Generic Attribute Profile (GATT)

- Generic Attribute Profile defines the way that two BLE devices transfer data back and forth using concepts called Services and Characteristics. It makes use of a generic data protocol called the Attribute Protocol (ATT), which is used to store Services, Characteristics and related data in a simple lookup table using 16-bit IDs for each entry in the table.

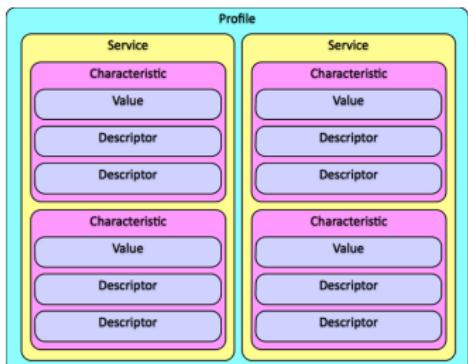


- GATT comes into play once a dedicated connection is established between two devices, meaning that you have already gone through the advertising process.



Bluetooth - Services and Profiles

- A Profile is a pre-defined collection of Services. The Heart Rate Profile, for example, combines the Heart Rate Service and the Device Information Service.
- Services break data up into logic entities, and contain specific chunks of data called characteristics. A service can have one or more characteristics, and each service distinguishes itself from other services with a unique numeric ID called a UUID, which can be either 16-bit (official BLE Services) or 128-bit (custom services).
- A Characteristic contains a single data point or an array of related data. For example: X/Y/Z values of an accelerometer.





ASCII Reminder

- ASCII characters (the symbols that we are use to reading) can be represented by a single byte (uint8_t).

ASCII TABLE

Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char
0	0	[NULL]	32	20	[SPACE]	64	40	@	96	60	`
1	1	[START OF HEADING]	33	21	!	65	41	A	97	61	a
2	2	[START OF TEXT]	34	22	"	66	42	B	98	62	b
3	3	[END OF TEXT]	35	23	#	67	43	C	99	63	c
4	4	[END OF TRANSMISSION]	36	24	\$	68	44	D	100	64	d
5	5	[ENQUIRY]	37	25	%	69	45	E	101	65	e
6	6	[ACKNOWLEDGE]	38	26	&	70	46	F	102	66	f
7	7	[BELL]	39	27	'	71	47	G	103	67	g
8	8	[BACKSPACE]	40	28	(72	48	H	104	68	h
9	9	[HORIZONTAL TAB]	41	29)	73	49	I	105	69	i
10	A	[LINE FEED]	42	2A	*	74	4A	J	106	6A	j
11	B	[VERTICAL TAB]	43	2B	+	75	4B	K	107	6B	k
12	C	[FORM FEED]	44	2C	:	76	4C	L	108	6C	l
13	D	[CARRIAGE RETURN]	45	2D	,	77	4D	M	109	6D	m
14	E	[SHIFT OUT]	46	2E	.	78	4E	N	110	6E	n
15	F	[SHIFT IN]	47	2F	/	79	4F	O	111	6F	o
16	10	[DATA LINK ESCAPE]	48	30	0	80	50	P	112	70	p
17	11	[DEVICE CONTROL 1]	49	31	1	81	51	Q	113	71	q
18	12	[DEVICE CONTROL 2]	50	32	2	82	52	R	114	72	r
19	13	[DEVICE CONTROL 3]	51	33	3	83	53	S	115	73	s
20	14	[DEVICE CONTROL 4]	52	34	4	84	54	T	116	74	t
21	15	[NEGATIVE ACKNOWLEDGE]	53	35	5	85	55	U	117	75	u
22	16	[SYNCHRONOUS IDLE]	54	36	6	86	56	V	118	76	v
23	17	[ENQ OF TRANS. BLOCK]	55	37	7	87	57	W	119	77	w
24	18	[CANCEL]	56	38	8	88	58	X	120	78	x
25	19	[END OF MEDIUM]	57	39	9	89	59	Y	121	79	y
26	1A	[SUBSTITUTE]	58	3A	:	90	5A	Z	122	7A	z
27	1B	[ESCAPE]	59	3B	:	91	5B	{	123	7B	{
28	1C	[FILE SEPARATOR]	60	3C	<	92	5C	\	124	7C	
29	1D	[GROUP SEPARATOR]	61	3D	=	93	5D]	125	7D	}
30	1E	[RECORD SEPARATOR]	62	3E	>	94	5E	^	126	7E	~
31	1F	[UNIT SEPARATOR]	63	3F	?	95	5F	-	127	7F	{DEL}

ASCII: American Standard Code For Information Interchange



Photon2 BLE - UART Service

```
1 // These UUIDs were defined by Nordic Semiconductor and are now the defacto standard for
2 // UART-like services over BLE. Many apps support the UUIDs now, like the Adafruit
3 // Bluefruit app.
4 const BleUuid serviceUuid("6E400001-B5A3-F393-E0A9-E50E24DCCA9E");
5 const BleUuid rxUuid("6E400002-B5A3-F393-E0A9-E50E24DCCA9E");
6 const BleUuid txUuid("6E400003-B5A3-F393-E0A9-E50E24DCCA9E");
7
8 BleCharacteristic txCharacteristic("tx", BleCharacteristicProperty::NOTIFY, txUuid,
9     serviceUuid);
10 BleCharacteristic rxCharacteristic("rx", BleCharacteristicProperty::WRITE_WO_RSP, rxUuid,
11     serviceUuid, onDataReceived, NULL);
12 BleAdvertisingData data;
13
14 //onDataReceived is used to receive data from Bluefruit Connect App
15 void onDataReceived(const uint8_t* data, size_t len, const BlePeerDevice& peer, void*
16     context) {
17     uint8_t i;
18
19     Serial.printf("Received data from: %02X:%02X:%02X:%02X:%02X:%02X \n", peer.address()
20         [0], peer.address()[1], peer.address()[2], peer.address()[3], peer.address()[4], peer
21         .address()[5]);
22     Serial.printf("Bytes: ");
23     for (i = 0; i < len; i++) {
24         Serial.printf("%02X ", data[i]);
25     }
26     Serial.printf("\n");
27     Serial.printf("Message: %s\n", (char *)data);
28 }
```



Photon2 BLE - UART Transmit Example

```
1 const int UART_TX_BUF_SIZE = 20;
2 uint8_t txBuf[UART_TX_BUF_SIZE];
3 uint8_t i;
4
5 SYSTEM_MODE(SEMI_AUTOMATIC); //Using BLE and not Wifi
6
7 void setup() {
8     Serial.begin();
9     waitFor(Serial.isConnected, 15000);
10
11    BLE.on();
12    BLE.addCharacteristic(txCharacteristic);
13    BLE.addCharacteristic(rxCharacteristic);
14    data.appendServiceUUID(serviceUuid);
15    BLE.advertise(&data);
16
17    Serial.printf("Photon2 BLE Address: %s\n", BLE.address().toString().c_str());
18 }
19
20 void loop() {
21     for(i=0;i<UART_TX_BUF_SIZE-1;i++) {
22         txBuf[i] = random(0x40,0x5B); //Capital ASCII characters plus @
23     }
24     txBuf[UART_TX_BUF_SIZE-1] = 0x0A;
25     txCharacteristic.setValue(txBuf, UART_TX_BUF_SIZE);
26     for(i=0;i<UART_TX_BUF_SIZE;i++) {
27         Serial.printf("%c",txBuf[i]);
28     }
29     delay(5000);
30 }
```



sprintf(): Formatted Print to a Buffer

sprintf() can be used to prepare a payload of data (buf) to be transferred between devices using BLE.

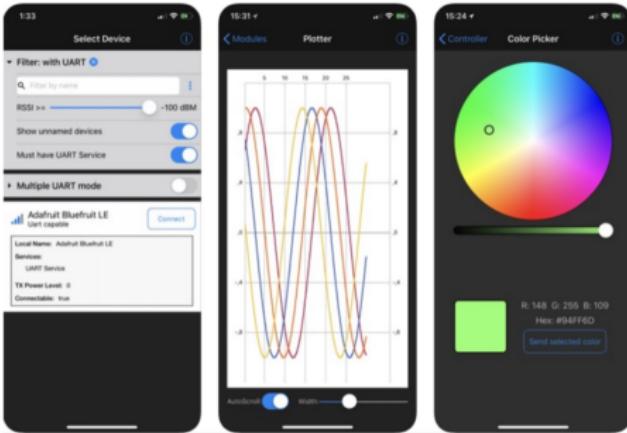
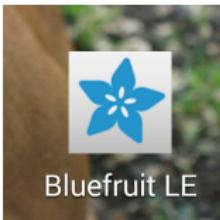
```
1 // sprintf does a formatted print to a buffer of type char[]
2
3 const int BUFSIZE = 50;
4 byte buf[BUFSIZE];
5 int people;
6 float dogs,avg;
7
8 void setup() {
9   Serial.begin(9600);
10  people = 5;
11  dogs = 13;
12 }
13
14 void loop() {
15  avg = dogs / people;
16  sprintf((char *)buf,"The %i people have on average %0.2f dogs \n",people, avg);
17  buf[BUFSIZE-1] = 0x0A; //ensure last character is a line feed (LF)
18  Serial.printf("Sending 'buf' contains the string: %s", (char *)buf);
19  txCharacteristic.setValue(buf, BUFSIZE);
20 }
```

Note: Windows treats a `\n` as a LF-CR (0x0D0A), if a LF is needed (e.g., for BLE) then it needs to be inserted manually:

```
1 buf[BUFSIZE-1] = 0x0A;
```



Install Bluefruit Connect App



Install the Bluefruit Connect app from the App Store and Google Play



Assignment: L14_01_BlueTooth

- Load Bluefruit Connect on your smart device. Using the code on the proceeding slides, establish and test BLE UART communications
- Attach the encoder and Neopixels to your Photon2.
- Review your NeoPixel ring/strip assignment (L05_02_NeoPixel) and copy the appropriate code to L14_01_BlueTooth
- Comment out sending a random string. Instead, when the encoder changes, send the NeoPixel position via BLE to Bluefruit Connect.
- Reset the encoder and NeoPixels to the appropriate state when a pixel number is received from Bluefruit Connect (zero to total number of pixels).
 - This can be accomplished by converting from pixel to encoder position and using myEnc.write() in onDataReceived()



Assignment: L14_BlueTooth - Colors

L14_01_BlueTooth (Continued)

- Plotter function in Bluefruit Connect:

- ① Every time the encoder moves, generate and change the pixels to a random color (R,G,B format, not Hex).
- ② Plot the pixel number and three RGB components on the Bluefruit Plotter.

- Controller -> Color Picker screen on Bluefruit Connect:

- ① Send a color to the Photon2.
- ② Identify in your code if ColorPicker string or general UART string is received.
- ③ If ColorPicker, then using bitwise left shift and OR to convert string to hex color similar to L09_02_RetrieveShow
- ④ Change your Neopixel color to match Color Picker

Plotter

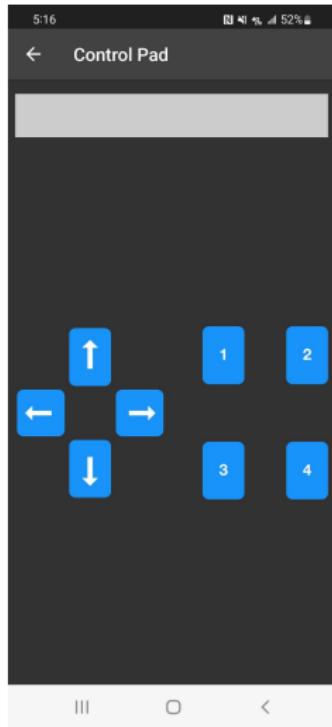
- The 'Plotter' utility can be used to plot incoming numeric data in a chart, without having to create a custom plotter code or application. It behaves similarly to the Serial Plotter in recent versions of the Arduino IDE.
- To plot one or more data streams to the plotter, send your numeric data in CSV format with one of the following separators:
 - '-' - Comma (0x2C)
 - '.' - Space (0x20)
 - ',' - Semicolon (0x3B)
 - Horizontal Tab (0x09), '\t' in code
- Each unique set of data samples must be terminated by a LINE FEED character (0x0A), which is usually represented as '\n' in code.
- Only numeric data should be sent over the BLE UART connection(s).

ColorPicker String
5 bytes plus CR

[!] [C] [byte red] [byte green] [byte blue] [CRC]



Assignment: L14_BlueTooth - Colors (EXTRA)



L14_01_BlueTooth (EXTRA)

- Experiment sending signals from the Bluefruit Connect Control Pad
- Use the Up/Down arrows to change the neopixel brightness
- Use the Left/Right arrows to cycle through a rainbow
- Code in a different neopixel effect for each of the number keys

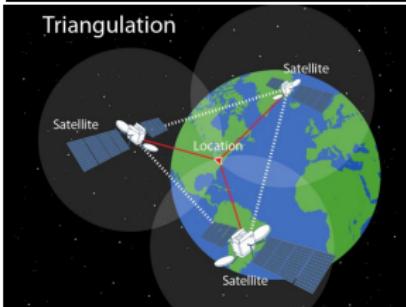


Global Positioning System





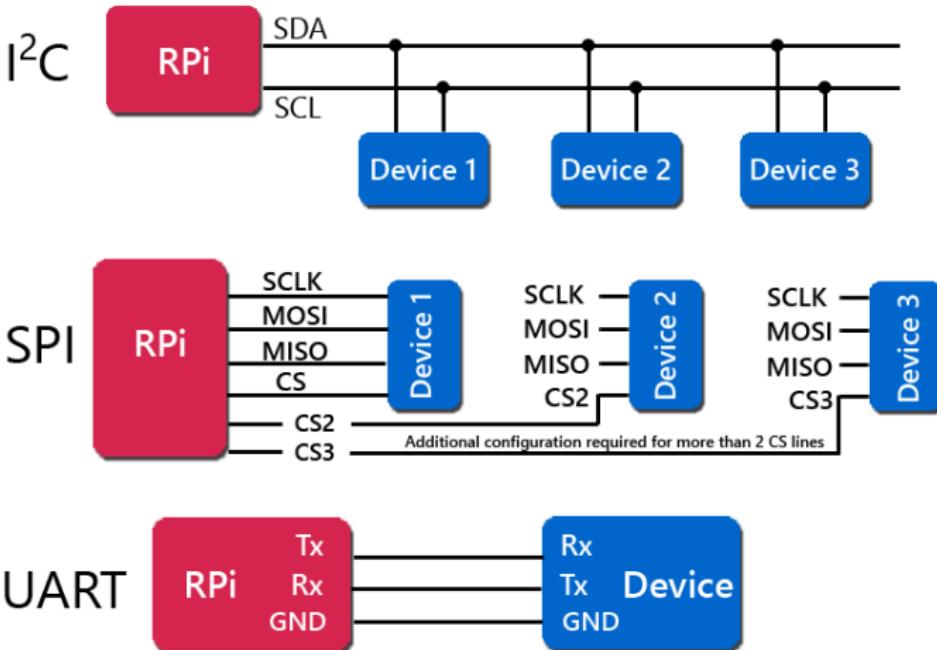
Global Positioning System



- 31 satellites at an altitude of 11000 miles, circling the earth every 718 minutes.
- Envisioned by Aerospace Corporation 1963
- First satellite 1973
- Open to commercial use 1985
- GPS receiver measures time it takes signal (at speed of light) to get from satellite to receiver.
- Uses triangulation from at least 4 satellites to obtain latitude, longitude, altitude, and time.
- GNSS is an international system of satellites that includes GPS, BDS, Galileo, GLONASS, IRNSS, QZSS and others



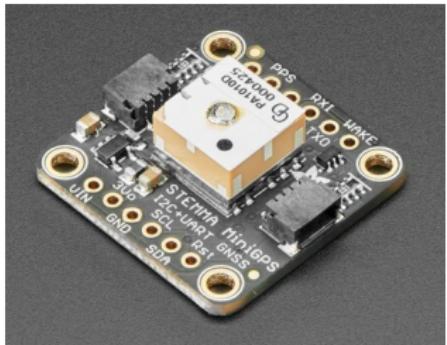
UART vs I²C vs SPI



MBTechWorks.com



Global Positioning System



- Miniature GPS module
- Houses a complete GPS/GNSS solution
- Both I2C and UART interfaces
- STEMMA interface for easy prototyping



Adafruit_GPS Library

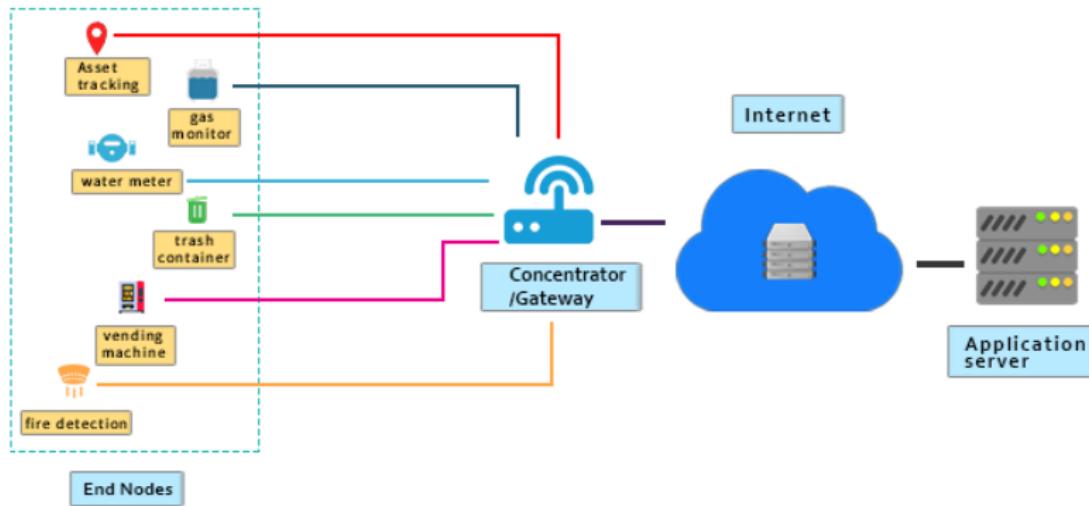
```
#GPGGA,202410.000,4042.6000,N,07400.4858,W,1,4,3.14,276.7,M,-34.2,M,,*63
#GPRMC,202410.000,A,4042.6000,N,07400.4858,W,0.08,161.23,160412,,,A*70
#GPGGA,202411.000,4042.5999,N,07400.4854,W,1,3,17.31,275.8,M,-34.2,M,,*5D
#GPRMC,202411.000,A,4042.5999,N,07400.4854,W,0.14,161.23,160412,,,A*7A
```

```
Time: 20:24:11.0
Date: 16/4/2012
Fix: 1 quality: 1
Location: 4042.5998N, 7400.4853W
Speed (knots): 0.14
Angle: 161.23
Altitude: 275.80
Satellites: 3
```

- Call `gps.read()` at the beginning of `void loop()`
- Then immediately call `GPS.parse(GPS.lastNMEA())` to make the data available
- When you need it, you can then access `GPS.latitude`, `GPS.longitude`, `GPS.speed`, etc.



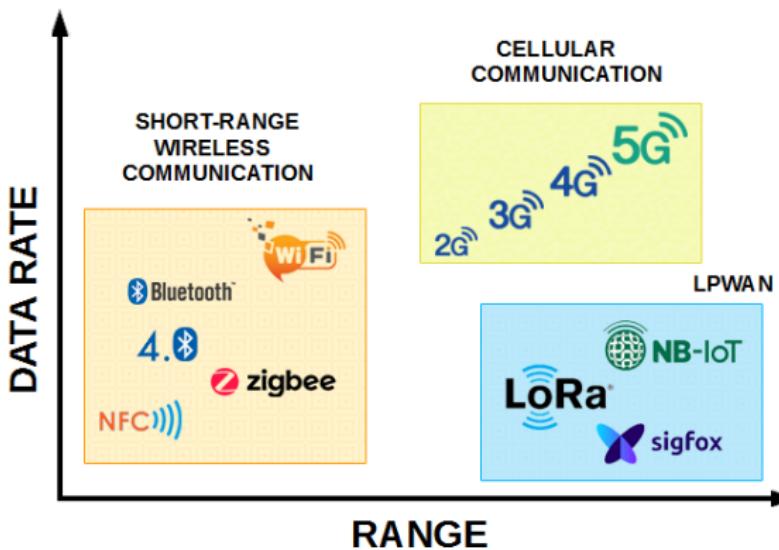
LoRa



LoRa is a long range, low power, inexpensive technology for Internet of Things



LoRa Range vs Data Rate



LoRa uses license-free sub-gigahertz radio frequency ISM bands in the deployed region such as 868 MHz in Europe and 915MHz in North America.



LoRa Features

LoRa has many desirable features:

- It has very wide coverage range about 5 km in urban areas and 15 km in suburban areas
- Battery lifetime up to 15 years
- One LoRa gateway takes care of thousands of nodes.
- Easy to deploy and low cost.
- Enhanced secure data transmission by embedded end-to-end AES128 encryption



RXLR896 LoRa Module

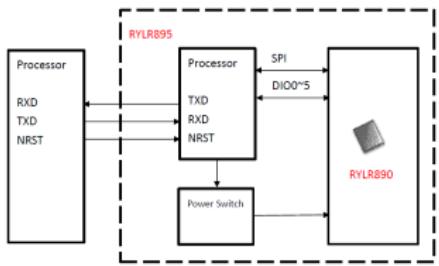
Features:

- Semtech SX1276 Engine
- Excellent blocking immunity
- Low receive current
- High sensitivity
- Control easily by AT commands
- 127 dB Dynamic Range RSSI
- Designed with integrated antenna
- AES128 Data encryption





AT Commands

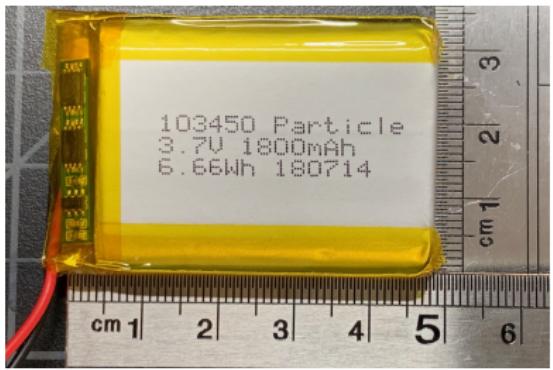


AT commands are commands which are used to control the modems where AT stands for Attention. These commands were derived from Hayes commands which were used by the Hayes smart modems. Every wireless modem requires an AT command to interact with a computer machine.

Communication between the Photon2 and RYLR896 takes place over UART (Serial1) using the same "Serial" commands that were used in Lesson 3 and Lesson 4.



Batteries - Going Mobile



- ① All Particle platforms have JST-PH pins for a Lithium Polymer (LiPo) battery
 - Always check wiring polarity
- ② Battery can be charged via USB port or V_{bus} .
- ③ Battery power is available on LiPo+ or 3.3V pins



Assignment: LoRaGPS

Features:

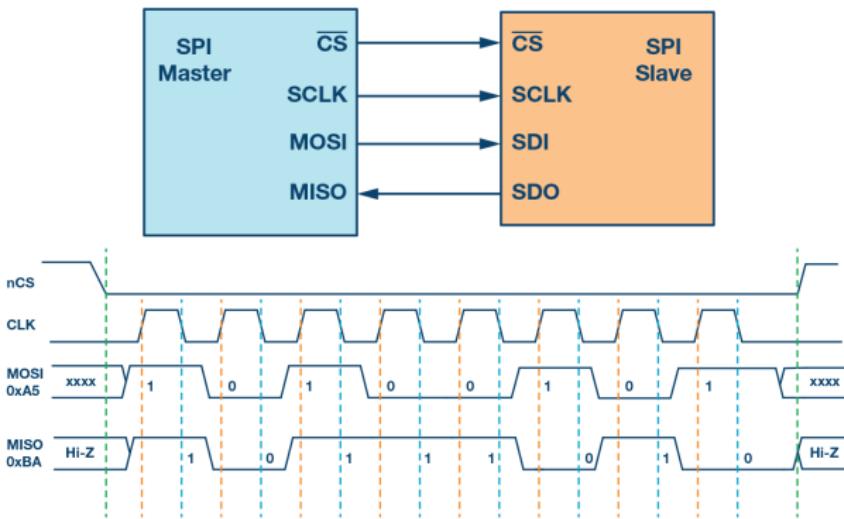


- Notebook:
schematic
- Fritzing diagram
- Wire your circuit
- Write the code

- ① Borrow a battery, GPS unit, and LoRa unit from the instructor
- ② Using the L14_00_GPS code, obtain GPS coordinates and display on OLED
- ③ Modify L14_04_LoRaGPS:
 - Integrate the LoRa, GPS, and OLED
 - Get your own RADIOADDRESS from instructors
 - Using IoT_Timer, turn on the D7 LED for 5 seconds when LoRa data received.
 - Display FUSE Sound/Particles to OLED
 - Send live GPS coordinates back to LoRa base-station
 - Find the distance you can go N/S/E/W and get a LoRa signal back to FUSE.
 - Class Trip: repeat at ABQ Biopark



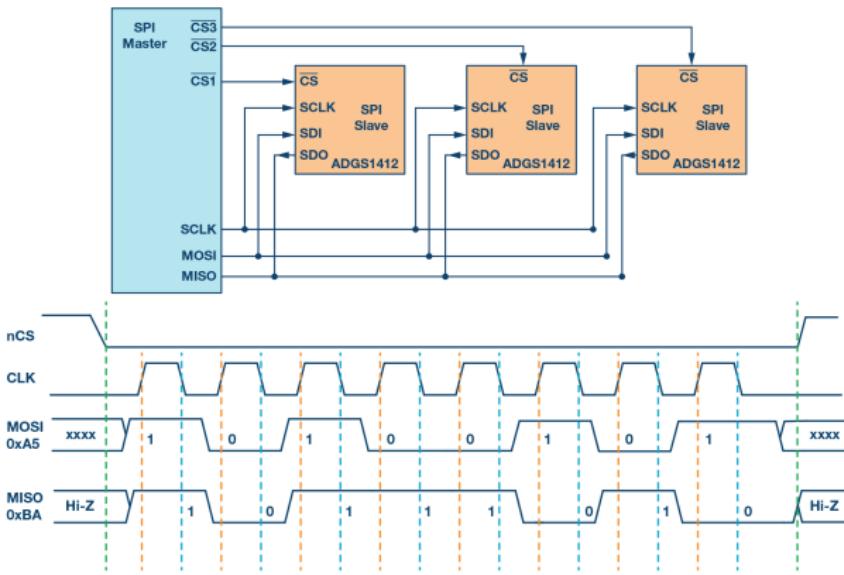
Serial Peripheral Interface



- Master Out, Slave In (MOSI) connects to Data In
- Master In, Slave Out (MISO) connects to Data Out



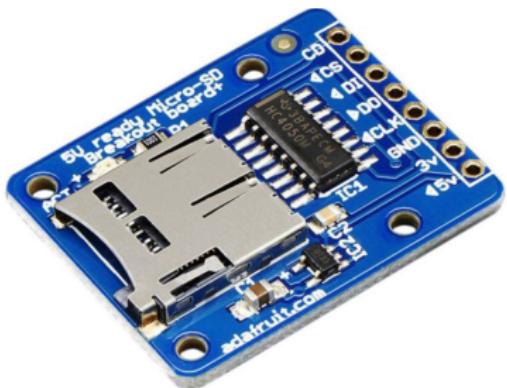
Multiple SPI Modules



- SPI uses the CS lines to select which peripheral is active.
- Having two SPI devices selected at the same time causes interference.
- In void setup(), always initialize all SPI devices as "off"
 - Note: CS is active LOW ("off" is HIGH)



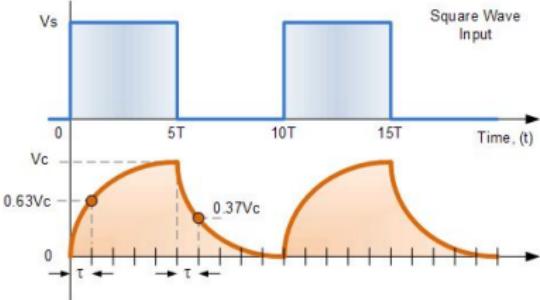
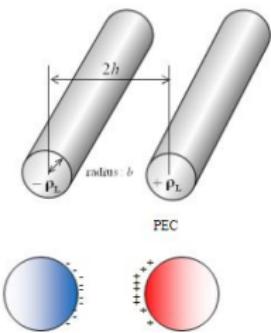
μSD Card Module



- ➊ SD cards are sensitive to interface to the pins
 - Keep wires short
 - Data lines need to be 3.3V, use level shifter is needed
- ➋ FAT16 or FAT32 format
 - File naming - 8.3 (e.g., myfile12.csv)
- ➌ Pinout
 - ◀ 5V - Power input(3.3V or 5V)
 - 3V output to power other devices
 - GND - Ground
 - ◀ CLK - Clock
 - ▶ DO - MISO
 - ◀ DI - MOSI
 - ◀ CS - Chip Select
 - CD - Card Detect



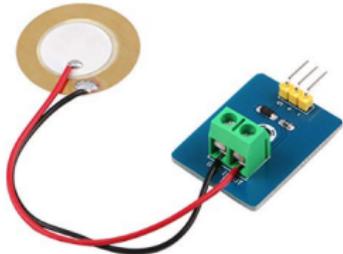
RC Time Constant



- Up until now, we have considered wires as ideal conductors; however:
 - Wires have non-zero resistance, longer and thinner wires have more resistance.
 - When two wires are close to each other, there is a parasitic capacitance between them.
- The time constant ($\tau = \frac{1}{RC}$) of an RC circuit determines the amount of time it takes a square wave input to reach 63% of its final value.
- Some communication protocols expect sharp transitions between 0 and 3.3V for clock and data signals.



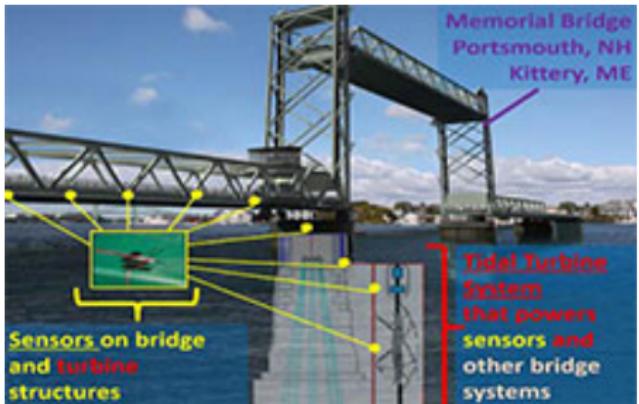
Piezoelectric Elements - Revisited



- The piezoelectric effect is the appearance of electrical potential (voltage) across the side of a crystal when subject to mechanical stress.
- Conversely, a crystal becomes mechanically stressed (deformed in shape) when a voltage is applied across opposite faces.
- By utilizing an `analogRead()`, the vibration (change in mechanical stress) can be monitored over time.



Structural Engineering Sensors





FAT File System - SDCard Project (Argon Only)

Feature	FAT32	NTFS
Maximum Partition Size	2TB	2TB
Maximum File Size	4GB	16TB
Maximum File Name	8.3 Characters	255 Characters
File/Folder Encryption	No	Yes
Fault Tolerance	No	Auto Repair
Security	Network Only	Local and Network
Compression	No	Yes
Compatibility	Win 95/98/2000/XP and the derivations	Win NT/2000/XP/Vista/7 and the later versions

The FAT (File Allocation Table) file system, originally designed in 1977 for floppy disks, is simple and robust. It offers good performance in very light-weight implementations, but does not deliver performance, reliability and scalability afforded by modern file systems (such as NTFS or exFAT).

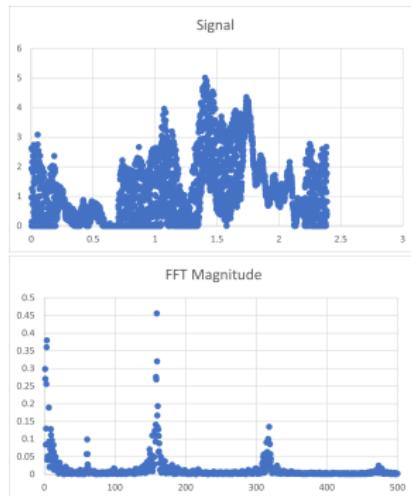
Note: FAT file name follows a 8.3 format (e.g., ABCDEFGH.txt). We will be appending two digits, so our base name can be up to 6 characters (e.g. FILE_BASE_NAME = "mydata" → mydata42.csv).



Galaxy S9+ Vibration Analysis

Using the FFT Tutorial in Class_Materials repository

	A	B	C	D	E
1	TimeStamp	Signal	Frequency	FFT Magnitude	Complex FFT
2	0.00061	2.62	0.4209321	2.000009766	4096.02
3	0.00119	1.93	0.8418642	0.836477508	-552.77950380473+1621.47055713326i
4	0.00177	0.96	1.2627963	0.298364661	-414.982558995766-448.522671528173i
5	0.00235	0.13	1.6837284	0.270681692	353.443826952842-427.069259698417i
6	0.00293	0	2.1046606	0.083873335	-72.9068609990069+155.532672030055i
7	0.003509	0	2.5255927	0.129856545	252.456289478309+83.6253876318606i
8	0.004089	0	2.9465248	0.255636434	-516.88842919695+83.210943362584i
9	0.004669	0	3.3674569	0.360085774	423.28074046682-603.882664071708i
10	0.005249	0.14	3.788389	0.379410535	88.80273300538+771.941714466294i
11	0.005829	1.26	4.2093211	0.04066392	-41.3210095359081-72.3054897410451i
12	0.006409	2.16	4.6302532	0.051383144	94.6397062012862-46.0135075977235i
13	0.006988	2.57	5.0511853	0.084507321	25.9352596801745-171.116717569232i
14	0.007568	1.89	5.4721175	0.041174283	36.0724144460193-76.2199128809511i
15	0.008148	0.73	5.8930496	0.04976769	-73.9953870941929-70.094447984849i



The Galaxy S9 vibrates at 159.11 Hz



Assignment: L14_DataXfer (Argon Only)



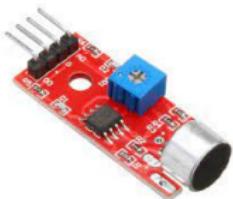
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

① L14_01_Vibration

- Connect the piezo sensor, a button, and a μ SD module to your Particle.
- Each time button is pressed, execute a loop 4096 times:
 - Every 500μ sec, collect piezoelectric data (without using a delay).
 - Save the piezo data and a timestamp (converting `micros()` to seconds) to a 2-dimensional array.
- When the loop is complete, write the timestamp and data to a file.
- Collect vibration data from the lathe, cell phone vibration, other machines at FUSE.
- Use Excel and the FFT Tutorial (`class_slides`) to resample graph data in frequency domain (This process will be reviewed as a class.).



Assignment: L14_DataXfer EXTRA



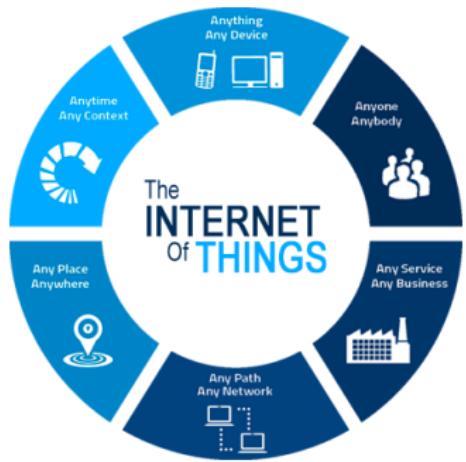
- Notebook: schematic
- Fritzing diagram
- Wire your circuit
- Write the code

① L14_01_Vibration

- Borrow a microphone.
- Install in place of the piezo sensor.
- Use Physics Toolbox Sensor Suite - Tone Generator to create a tone of a specific frequency.
- Record/save with the Photon2, and create an FFT



Module 14 Review



- Learning Objectives

- 1 Bluetooth
- 2 GPS
- 3 UART / SPI
- 4 LoRa

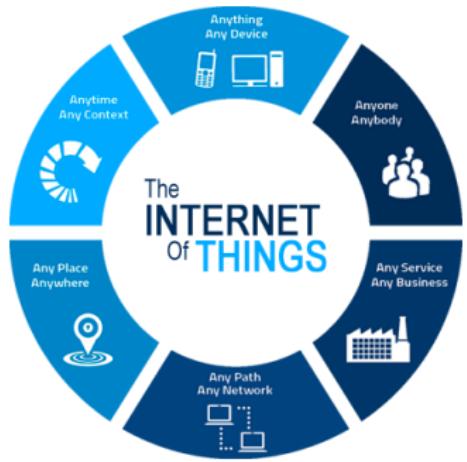
- Additional Items

- 1 3D Modeling Lesson 6 - ESP32-CAM
- 2 Quiz 10

Module 15 - In the Wild



Module 15 Objectives



Learning Objectives

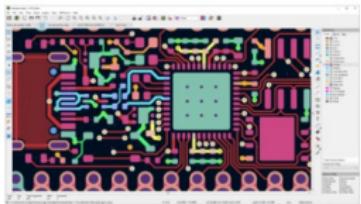
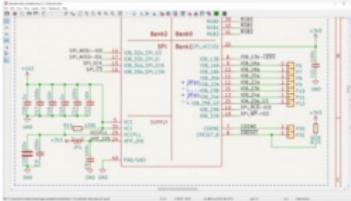
- ① PCB Design
- ② Power and Reset
- ③ Watchdogs
- ④ Power Management
- ⑤ Cloud Flash
- ⑥ Hosting MQTT/NodeRed



KiCad: Breadboard are good, but PCBs are better

Schematic Capture

KiCad's Schematic Editor supports everything from the most basic schematic to a complex hierarchical design with hundreds of sheets. Create your own custom symbols or use some of the thousands found in the official KiCad library. Verify your design with integrated SPICE simulator and electrical rules checker.



PCB Layout

KiCad's PCB Editor is approachable enough to make your first PCB design easy, and powerful enough for complex modern designs. A powerful interactive router and improved visualization and selection tools make layout tasks easier than ever.

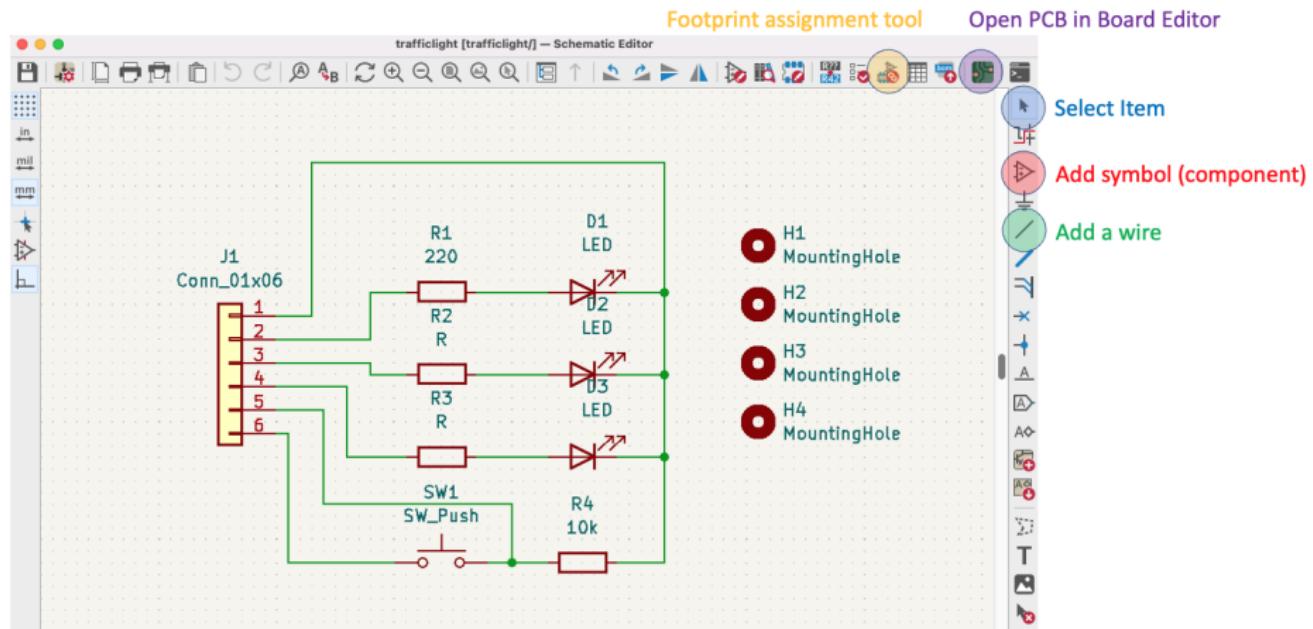
3D Viewer

KiCad's 3D Viewer allows easy inspection of your PCB to check mechanical fit and to preview your finished product. A built-in raytracer with customizable lighting can create realistic images to show off your work.





Start with schematics





Rich library of components

Components or Modules

The screenshot shows the EAGLE software interface with three windows open:

- Top Window:** Shows a search results list for "2N3904". The first item is selected, showing its description: "BJT transistor symbol, 0.2A IC, 40V Vce, Small Signal NPN Transistor, 200mA IC, 40V Vce, Dual NPN/NPN Transistor, 200mA IC, 40V Vce, Dual NPN/NPN Transistor, 0.2A IC, 40V Vce, Small Signal NPN Transistor, 0.2A IC, 40V Vce, Dual NPN/NPN Transistor, 200mA IC, 40V Vce, Dual NPN/NPN Transistor, 200mA IC, 40V Vce, Dual NPN/NPN Transistor".
- Middle Window:** Shows a detailed schematic symbol for an InvenSense MPU-6050 sensor. It has various pins labeled: SDA (pin 2), SCL (pin 3), ADO (pin 9), INT (pin 12), AUX_SDA (pin 6), AUX_SCL (pin 5), CSYNC (pin 11), CLKIN (pin 1), GND (pin 14), and VDD (pin 13). It also includes labels for "CIRCUIT REGULATOR" and "MPU-6050".
- Bottom Window:** Shows a PCB preview window titled "[Default] Package, 1x 101 Pin TO-92_Inline". It displays the component footprint with the text "REF**" above it and "TO-92_Inline" below it. A red arrow points from the text "PCB Preview" to this window.

PCB Preview



Select a footprint for each component

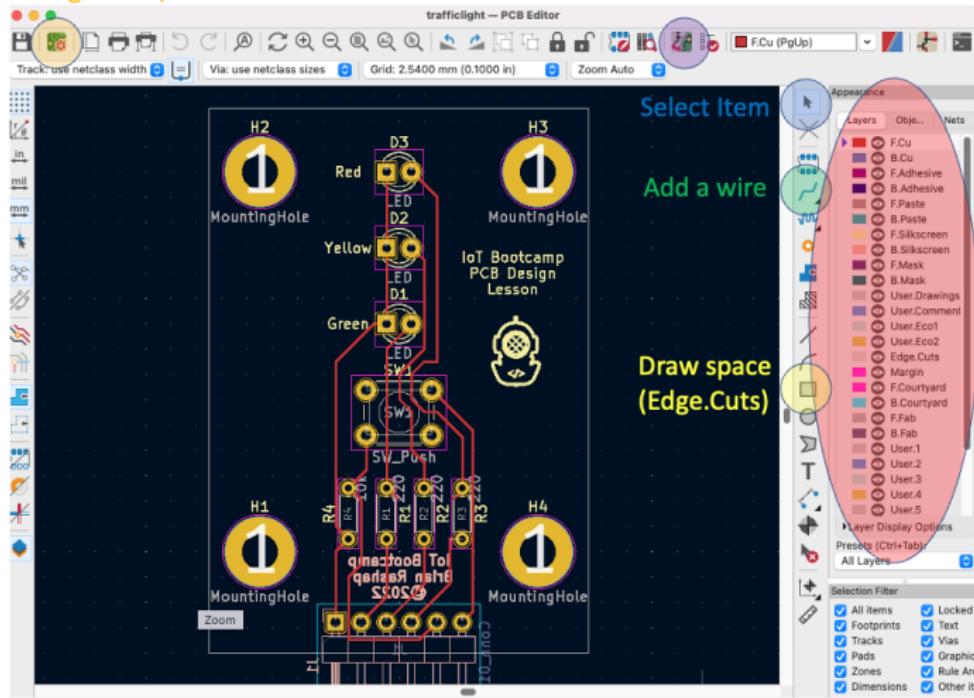
The screenshot shows the KiCad software interface for selecting component footprints. The main window displays a schematic diagram of a simple circuit with a resistor (R1), a diode (D1), and a LED (D2). A callout points from the text "Right Click" to the LED component in the schematic. The "Symbol Properties" dialog is open, showing the component properties for D1, including its name, value, and footprint. The footprint is currently set to "LED_THT/LED_D3.0mm". The "Footprint Library Browser" dialog is also open, showing a list of available footprint libraries. A red arrow points from the text "Library" to the "Footprint Library Browser" dialog. The bottom status bar shows the current grid settings as "Grid: 1.2700 mm (0.0500 in)".



Generate PCB, Route Wires

Edit board setup including layers, design rules, and various defaults

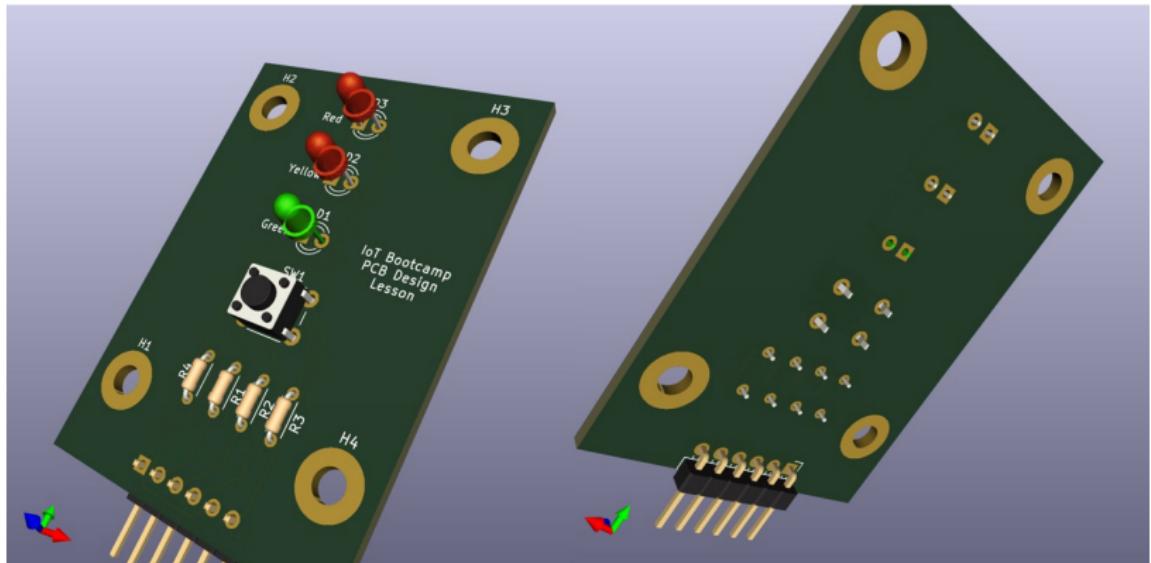
Update PCB with changes made to schematic



Layers (including
hide/unhide)



3D View





Import into KiCad

Import Symbols

Using the KiCad (*.lib) file:

1. In KiCad, go to **Tools > Edit Schematic Symbols**.
2. Click on **Preferences > Manage Symbol Libraries**.
3. On the **Global Libraries** tab, click on **Browse Libraries** (the *small folder icon* below) and select the .lib file. Then click **Open**. The library will appear, click **OK**.
4. Toggle the search tree on, and navigate to the symbol you imported. Double-click over it to open the file.

Import Footprints

Using the *.kicad_mod file:

1. In KiCad, go to **Tools > Edit PCB Footprints**.
2. Click on **Preferences > Manage Footprint Libraries**.
3. On the **Global Libraries** tab, click on **Browse Libraries** (the *small folder icon* below) and navigate to the **Folder** of the downloaded .kicad_mod file. Then click **Open**, and the library will appear. If the path doesn't have the same name, you can rename it as the part.
4. In the table, make sure that the Plugin Type is set to **KiCad**. Then click **OK**.
5. Toggle the search tree on, and navigate to the footprint you imported. Double-click over it to open the file.

Using the *.mod file:

1. Follow the same steps above from step 1 to step 3.
2. In the table, make sure that the Plugin Type is set to **Legacy**. Then click **OK**.
3. Toggle the search tree on, and navigate to the footprint you imported. Double-click over it to open the file.



Assignment: L15_TrafficPCB

Open PCB in Board Editor

The screenshot shows the Open PCB software interface. On the left, a schematic diagram is displayed with components J1 (Conn_01x06), R1-R4 (resistors), D1-D3 (LEDs), SW1 (push button), and various connection lines. On the right, a board editor view shows a green printed circuit board (PCB) with component footprints and mounting holes. A context menu is open over the board editor, with options like "Select item", "Add symbol (component)", and "Add a wire". Below the board editor, a table titled "Symbol : Footprint Assignments" lists component symbols and their corresponding footprint assignments:

Symbol	Footprint Assignment
1	D1 - LED : LED_THT:LED_D3.0mm
2	D2 - LED : LED_THT:LED_D3.0mm
3	D3 - LED : LED_THT:LED_D3.0mm
4	H1 - MountingHole : MountingHole:MountingHole_3.5mm_Pad
5	H2 - MountingHole : MountingHole:MountingHole_3.5mm_Pad
6	H3 - MountingHole : MountingHole:MountingHole_3.5mm_Pad
7	H4 - MountingHole : MountingHole:MountingHole_3.5mm_Pad
8	J1 - Conn_01x06 : Connector_PinHeader_2.54mm:PinHeader_1x06_P2.54mm_Horizontal
9	R1 - 220 : Resistor_THT:R_Axial_DIN0204_L3.6mm_D1.6mm_P5.08mm_Horizontal
10	R2 - R : Resistor_THT:R_Axial_DIN0204_L3.6mm_D1.6mm_P5.08mm_Horizontal
11	R3 - R : Resistor_THT:R_Axial_DIN0204_L3.6mm_D1.6mm_P5.08mm_Horizontal
12	R4 - 10k : Resistor_THT:R_Axial_DIN0204_L3.6mm_D1.6mm_P5.08mm_Horizontal
13	SW1 - SW_Push : Button_Switch_THT:SW_PUSH_6mm_H5mm



EN and RST pins

The Photon2 has two pins that are extremely useful in real world situations:



① EN pin

- The EN pin is not a power pin, per se, but it controls the 3V3 power.
- Device enable pin is internally pulled-up. To disable the device (force the device into a deep power-down state), connect this pin to GND.
- This pin is essentially an on/off pin.

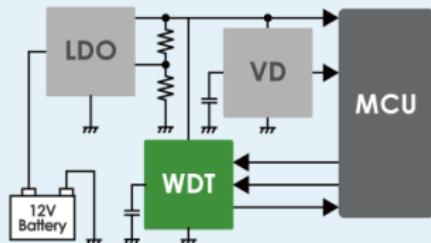
② RST pin

- Active-low system reset input. This pin is internally pulled-up.



Watchdog Timer

e.g. Circuits peripheral to the MCU and WDT
(in an automotive environment)



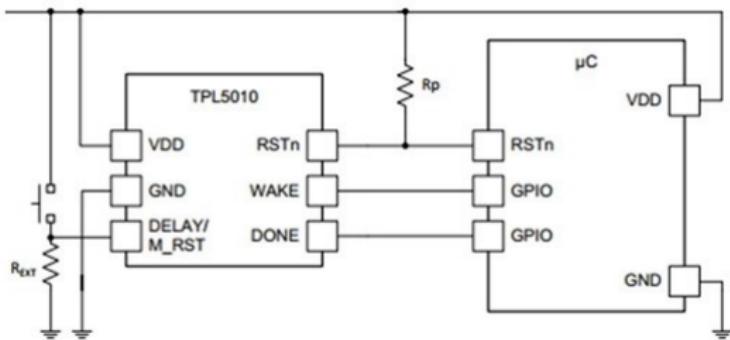
The WDT takes the role of “watchdog” and watches over MCU operation at all times.



The watchdog timer communicates with the MCU at a set interval. If the MCU does not output a signal, outputs too many signals or outputs signals that differ from a predetermined pattern, the timer determines that the MCU is malfunctioning and sends a reset signal to the MCU.



Hardware Watchdog Timers - TPL5010



The timeout frequency is set by resistor R_{EXT} using a formula from the data sheet.

Timeout Interval	Calculated Resistance
1 minute	22 Ω
5 minutes	43 Ω
30 minutes	92 Ω
1 hour	125 Ω
2 hours	170 Ω



Application Watchdog

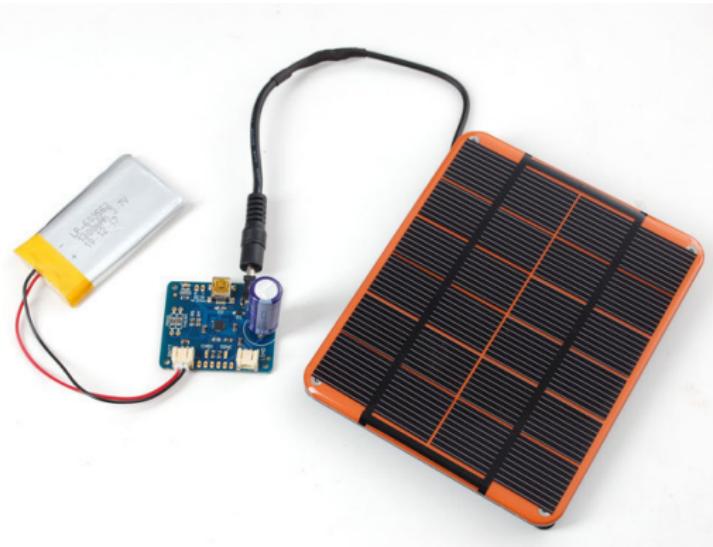
The Photon2 also has a watchdog timer that can be implemented in code. It is not as robust as the hardware timer, but better than nothing.

```
1 // Prototype
2 // ApplicationWatchdog(unsigned timeout_ms, std::function<void(void)> fn, unsigned
3 // stack_size=DEFAULT_STACK_SIZE);
4
5 // Global variable to hold the watchdog object pointer
6 ApplicationWatchdog *wd;
7
8 void watchdogHandler() {
9     // Do as little as possible in this function, preferably just a reset
10    System.reset(RESET_NO_WAIT);
11 }
12
13 void setup() {
14     // Start watchdog. Reset the system after 60 seconds if the application is unresponsive
15     // The stack_size default is 512, but this is too small. Use at least 1536.
16     wd = new ApplicationWatchdog(60000, watchdogHandler, 1536);
17 }
18
19 void loop() {
20     while (some_long_process_within_loop) {
21         ApplicationWatchdog::checkin(); // resets the AWDT count
22     }
23 } // AWDT count reset automatically after loop() ends
```



Solar Charging

Should be easy, but isn't.





Power Management

`System.sleep()` can be used to lower power consumption and increase battery life when the Particle is only needed intermittently to interact with the environment.

	Device	GPIO	RTC	Analog	Serial	BLE	Network
	T523 Eval	139 uA	139 uA	140 uA	564 uA	214 uA	21.7 mA
	T402 Eval	114 uA	114 uA	117 uA	530 uA	186 uA	16.9 mA
	Boron 2G/3G	171 uA	174 uA	178 uA	610 uA	494 uA	16.4 mA
	Boron LTE	127 uA	128 uA	130 uA	584 uA	442 uA	14.2 mA
	B402 SoM	48 uA	47 uA	48 uA	557 uA	130 uA	9.5 mA
	STOP	ULTRA_LOW_POWER	HIBERNATE				
Relative power consumption	Low	Lower	Lowest	P2	579 uA	572 uA	
Relative wake options	Most	Some	Fewest	Argon	82 uA	81 uA	520 uA
Execution continues with variables intact	✓	✓		Electron	2.42 mA	2.55 mA	n/a
				Photon	2.76 mA	2.83 mA	n/a
					n/a	n/a	n/a
					n/a	n/a	n/a



Ultra Low Power example

The below code places the Photon2 in Ultra_Low_Power mode, enabling it to be awakened either by a RISING signal on Pin D0 or after the time specified by the variable sleepDuration.

```
1 void sleepULP() {
2     SystemSleepConfiguration config;
3     config.mode(SystemSleepMode::ULTRA_LOW_POWER).gpio(D0,RISING).duration(sleepDuration);
4     SystemSleepResult result = System.sleep(config);
5     delay(1000);
6     if (result.wakeupReason() == SystemSleepWakeUpReason::BY_GPIO) {
7         Serial.printf("Awakened by GPIO %i\n",result.wakeupPin());
8     }
9     if (result.wakeupReason() == SystemSleepWakeUpReason::BY_RTC) {
10        Serial.printf("Awakened by RTC\n");
11    }
12 }
13 /*
14 * Other wake-up modes (These modes DO NOT work with the Photon2)
15 * config.mode(SystemSleepMode::ULTRA_LOW_POWER).analog(pin, value, mode);
16 *     mode can be: ABOVE, BELOW, or CROSS
17 * config.mode(SystemSleepMode::ULTRA_LOW_POWER).uart(Serial1);
18 *     note: Serial can not be used for wake-up
19 * config.mode(SystemSleepMode::ULTRA_LOW_POWER).ble();
20 * config.mode(SystemSleepMode::ULTRA_LOW_POWER).network(NETWORK_INTERFACE_WIFI_STA);
21 */
```

The Photon2 only has 2 options for wake: GPIO and RTC.



Reminder: Not Everything is About Voltage

Recall $P = V * I$, it is possible to be current limited.

Parameter	Symbol	Min	Typ	Peak	Unit
Operating Current (uC on, peripherals and radio disabled)	I_{idle}	21.4	23.2	23.8	mA
Operating Current (uC on, BLE advertising)	I_{ble_adv}	54.7	58.7	70.7	mA
Operating Current (uC on, radio connected to access point)	$I_{wifi_conn_ap}$	54.6	60.5	265	mA

The 3.3V regulator can supply 500mA. Typical power consumption:

- The Photon2 connected to Wifi can draw up to 265mA.
- Each GPIO used as an output can supply 4 – 12mA.
- Each NeoPixel uses up to 60mA at full brightness.
- Seeed sensors: dust - 90mA, AQ sensor - 60mA
- Plant Watering Pump: 130mA

V_{USB} can supply³ up to 1500mA⁴. External supply can add more current.

³It is all about power, so 1500mA at 5V is 2250mA at 3.3V

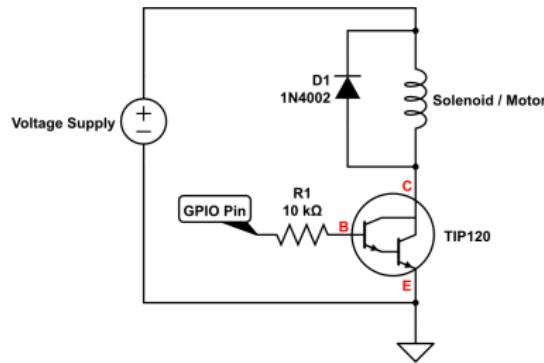
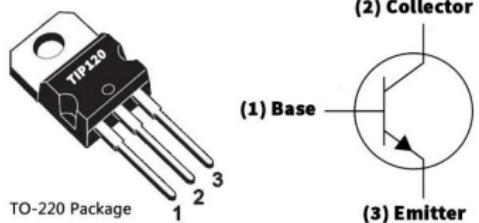
⁴Specific amount depends on type of USB port used (2.0 vs 3.x vs USB-C)



Assignment L15_01_HelloSolenoid

Similar to the Darlington Array used by the Stepper Motor, an individual Darlington transistor can be used to amplify current for a solenoid, motor, etc.

TIP120 Pinout



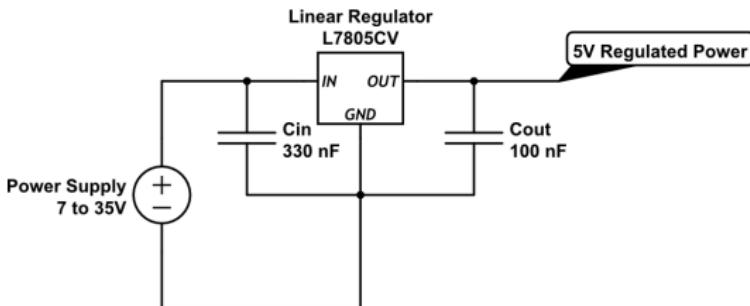
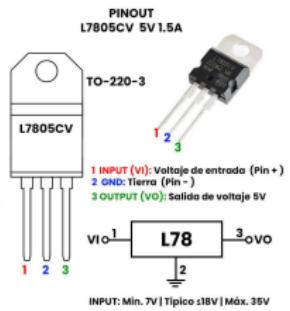
Assignment:

- Create a fritzing diagram of the above circuit.
- Borrow a solenoid from instructor and the Wire the circuit
- Use HelloWorld code to actuate the solenoid



Linear Voltage Regulator

The L7805CV is a three-terminal positive voltage regulator that provides a fixed output voltage of 5 volts. It is commonly used in electronic circuits to ensure a stable power supply and protect sensitive components from voltage fluctuations. This provides a maximum of 1.5A.



Alternatives:

- LM317 - adjustable (1.2V to 37V) voltage regulator
- AMS1117 - 3.3V voltage regulator



Cloud Flash

During the deployment phase, it isn't convenient to have to hook up a USB cable to push updates. The Particle ecosystem allows for sending code over-the-air (OTA).

```
>cloud
Particle: Cloud Compile                               recently used
Particle: Cloud Flash                                other commands
```

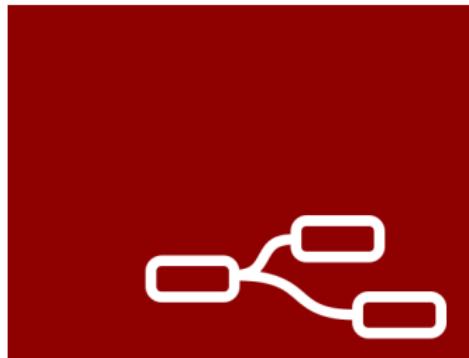
- Cloud Compile - compile your program and download the binary
- Cloud Flash - compile and flash it to the selected device OTA

The OTA operations require:

- The device is connected to the Particle Cloud (breathing cyan)
- The computer is into the same account that claimed the device.
- The DeviceID is set to the device name.



Local MQTT Server





Install Mosquitto (Windows - PowerShell)

```
1 // On Windows go to mosquitto.org/download
2
3 // Open three PowerShell windows and set each of them to
4 cd c:\'Program Files'\mosquitto
5
6 // PowerShell window #1: Start Mosquitto
7 .\mosquitto
8
9 // PowerShell window #2: Subscribe to the test topic (feed)
10 .\mosquitto_sub -h localhost -t feeds/test
11
12 // PowerShell window #3: Publish "Hello World"
13 .\mosquitto_pub -h localhost -t feeds/test -m "Hello World"
```



Install Mosquitto (Windows - Git Bash)

```
1 // On Windows go to mosquitto.org/download
2
3 // Open three PowerShell windows and set each of them to
4 cd /c/'Program Files'/mosquitto
5
6 // PowerShell window #1: Start Mosquitto
7 ./mosquitto
8
9 // PowerShell window #2: Subscribe to the test topic (feed)
10 ./mosquitto_sub -h localhost -t feeds/test
11
12 // PowerShell window #3: Publish "Hello World"
13 ./mosquitto_pub -h localhost -t feeds/test -m "Hello World"
```



Install Mosquitto (Mac / Linux)

```
1 // On Windows go to mosquitto.org/download
2
3 // On Mac using Homebrew (Intel Processor)
4 brew install mosquitto
5
6 // On Mac using Homebrew (Apple M1/2/3 Processor)
7 arch -arm64 brew install mosquitto
8
9 // On Linux (Debian and Ubuntu)
10 sudo apt-get install mosquitto mosquitto-clients
11
12 // Open three terminals:
13
14 // Terminal #1: Start Mosquitto
15 sudo /usr/local/sbin/mosquitto -c /usr/local/etc/mosquitto/mosquitto.conf
16
17 // Terminal #2: Subscribe to the test topic (feed)
18 mosquitto_sub -h localhost -t feeds/test
19
20 // Terminal #3: Publish "Hello World"
21 mosquitto_pub -h localhost -t feeds/test -m "Hello World"
```



Install Node-Red (Basic)

```
1 // Start With Installing nodejs:  
2  
3 // On Windows go to nodejs.org/en/  
4  
5 // On Mac using Homebrew (Intel Processor)  
6 brew install node  
7  
8 // On Mac using Homebrew (Apple M1/2/3 Processor)  
9 arch -arm64 brew install node  
10  
11 // On Linux (Debian and Ubuntu)  
12 sudo apt install nodejs npm  
13  
14 // VERIFY: In terminal or PowerShell, verify using  
15 node -v  
16 npm -v  
17  
18 // On Windows (Powershell):  
19 Set-ExecutionPolicy -Scope CurrentUser -ExecutionPolicy Unrestricted  
20  
21 // Install Node-RED (all platforms)  
22 npm install -g --unsafe-perm node-red  
23  
24 // Start node-red  
25 node-red
```

In a browser URL bar, go to localhost:1880

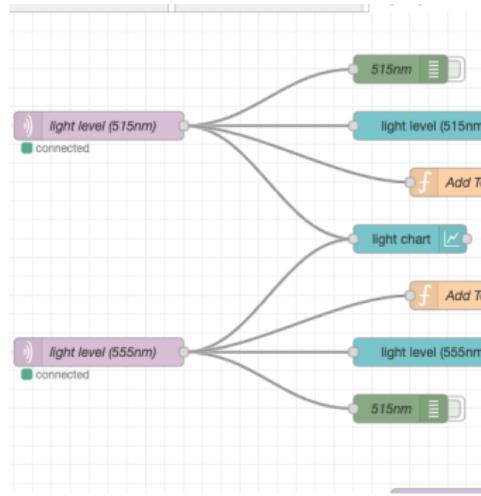


Node Red Dashboard





Node Red MQTT Node



Edit mqtt in node

Delete	Cancel	Done
Properties		
Server	ddciot.us	
Action	Subscribe to single topic	
Topic	hydro/ch4	
QoS	2	
Output	auto-detect (parsed JSON object, string or bu	
Name	light level (515nm)	



Node Red MQTT Connection

Edit mqtt in node > Edit mqtt-broker node

Delete Cancel Update

Properties

Name: dddiot.us

Connection Security Messages

Server: mqtt.dddiot.us Port: 1883

Connect automatically
 Use TLS

Protocol: MQTT V3.1.1

Client ID: Leave blank for auto generated

Keep Alive: 60

Session: Use clean session

Edit mqtt in node > Edit mqtt-broker node

Delete Cancel Update

Properties

Name: dddiot.us

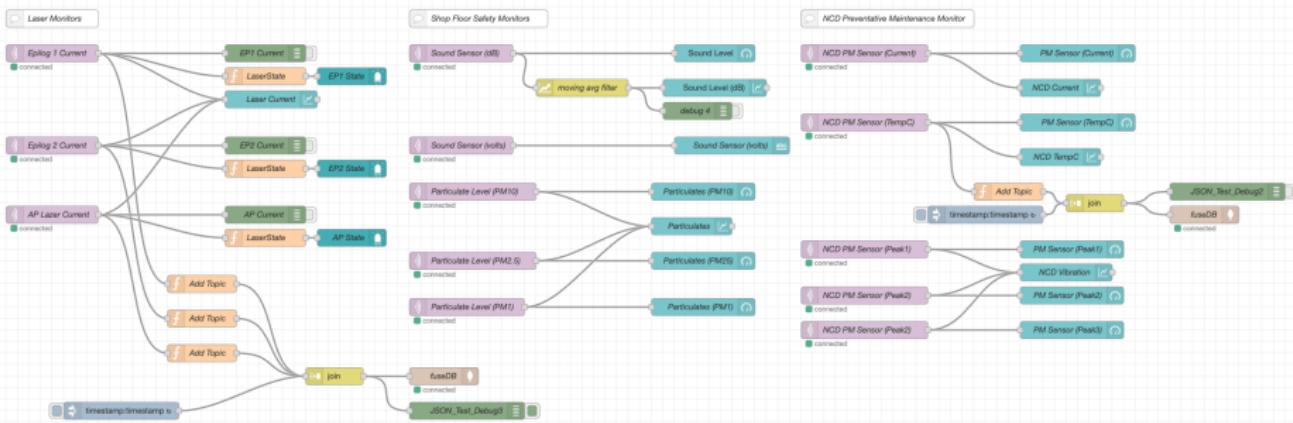
Connection Security Messages

Username: fuse

Password: *****

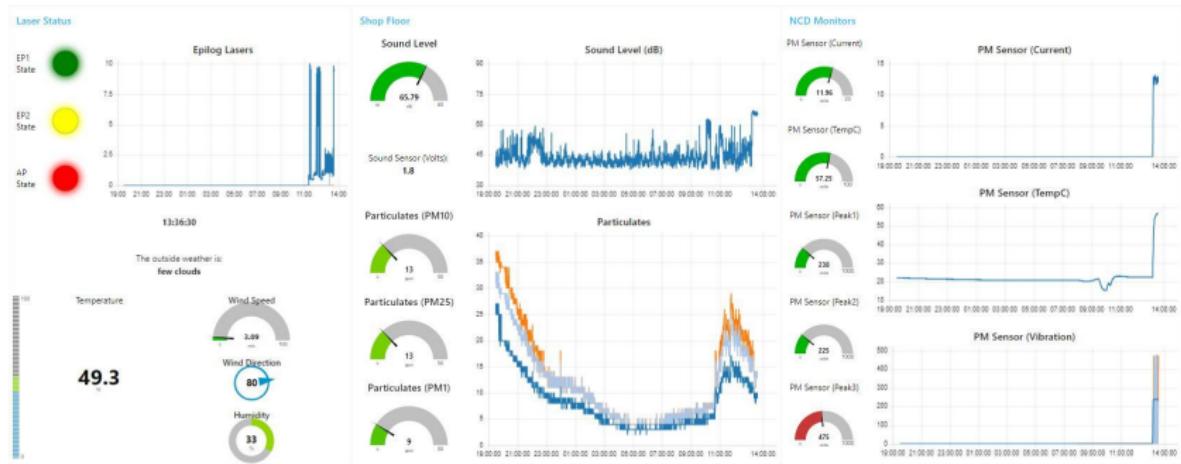


Node Red Smart Fuse Flow





Node Red Smart Fuse Dashboard





Install Mosquitto MQTT Broker (Detailed: Linux)

Install Mosquitto

```
1 // install Mosquitto broker and client
2 sudo apt-get install mosquitto mosquitto-clients
3 // start the broker and enable at startup
4 sudo systemctl enable mosquitto.service
5 sudo systemctl start mosquitto.service
6 // open new terminal window
7 mosquitto_sub -h localhost -t feeds/test
8 // in the original terminal
9 mosquitto_pub -h localhost -t feeds/test -m "Hello World"
10 // create a password file - replace bob with your username
11 // the -c overwrites existing file, leave off to append
12 sudo mosquitto_passwd -c /etc/mosquitto/passwd bob
```

Create and edit file: /etc/mosquitto/conf.d/default.conf

```
1 // File: /etc/mosquitto/conf.d/default.conf
2 allow_anonymous false
3 password_file /etc/mosquitto/passwd
4 listener 1883
```

Test the username and password

```
1 // restart mosquitto
2 sudo systemctl restart mosquitto
3 // restart both sub and pub using username and password above
4 mosquitto_sub -h localhost -t feeds/test -u "bob" -P "password"
5 mosquitto_pub -h localhost -t feeds/test -m "Hello World" -u "bob" -P "password"
```



Node-RED (Detailed: Linux)

```
1 // Install nodejs and npm
2 sudo apt install nodejs npm
3 node -v // validate it was installed correctly
4
5 // Install Node-RED
6 sudo npm install -g --unsafe-perm node-red
7
8 // Start node-red service on reboot using PM2
9 sudo npm install -g pm2
10
11 // find and use the correct node-red path
12 which node-red
13 pm2 start /usr/local/bin/node-red -- -v
14 pm2 save
15 pm2 startup // and follow instructions
16
17 // some systems might require
18 pm2 startup systemd
```



Securing Node-Red (Detailed: Linux)

```
1 // Install the node-red-admin package
2 sudo npm install -g --unsafe-perm node-red-admin
3 // Create a password hash
4 node-red-admin hash-pw
```

Edit `./node-red/settings.js`

```
1 // File: ~/.node-red/settings.js
2 // Find and uncommnet the adminAuth section using the hash
3 adminAuth: {
4   type: "credentials",
5   users: [
6     {
7       username: "admin",
8       password: "$2a$08$zZWTXTja0fB1pzD4sHCMy0CMYz2Z6dNbM6t18sJogENOMcxWV9DN.",
9       permissions: "*"
10    },
11    {
12      username: "bob",
13      password: "$2b$08$W7tKOfdNkm6eZUucgFMoauV1qPwf60MnGzumCc/B8Xj/FUjs8SVMq",
14      permissions: "*"
15    }
16 },
```

Restart node-red to allow all changes to take effect

```
1 sudo systemctl restart node-red
```



Accessing from other computers (on same network)

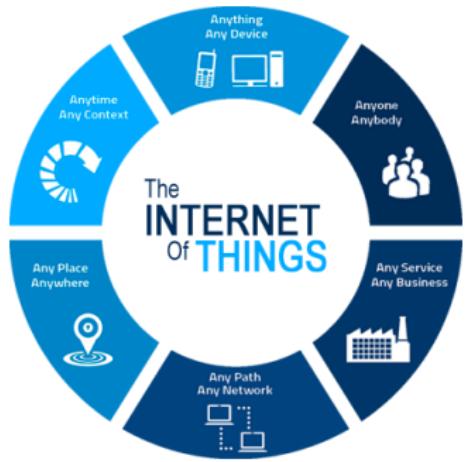
```
1 // Find your systems IP Address
2 sudo apt install net-tools
3 ifconfig
4
5 // Open ports from Mosquitto and Node-Red
6 sudo ufw allow 1880 // Node-Red port
7 sudo ufw allow 1883 // MQTT port
8 sudo ufw enable      // Turn on firewall
9 sudo ufw status
```

- Devices and publish/subscribe to your Mosquitto MQTT Broker if on the same network using your computer's IP address and Port: 1883.
- Access Node-Red from browser on same network using IPAddress:1880

Note: To access anywhere, you need to setup on a cloud service such as DigitalOcean.



Module 15 Review



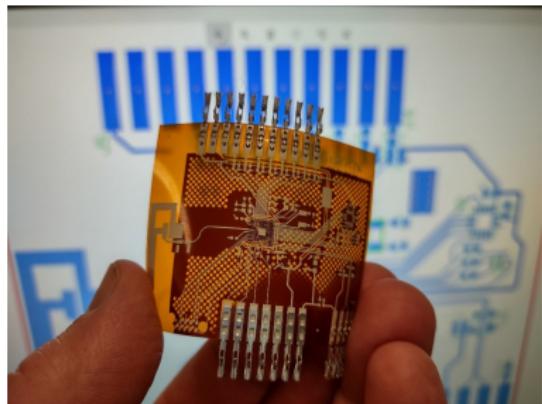
Learning Objectives

- ① PCB Design
- ② Power and Reset
- ③ Watchdogs
- ④ Power Management
- ⑤ Cloud Flash
- ⑥ Hosting MQTT/NodeRed

Module 16: FHE and Debug Mode



Flexible Hybrid Electronics (NextFlex A21)



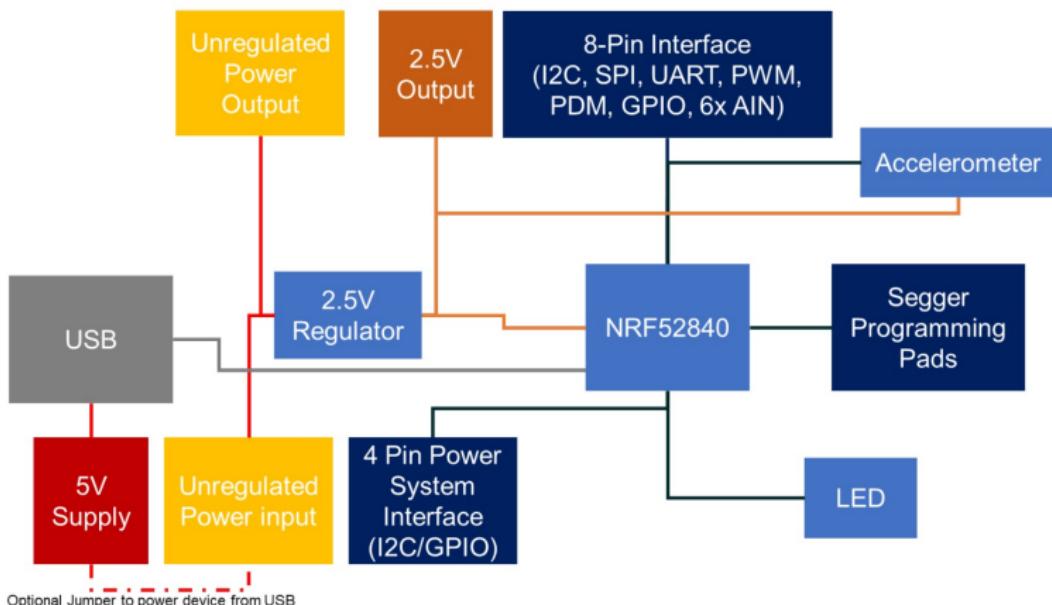


Why Flexible Hybrid Electronics

- Structural and/or Conformal Electronics
 - Printing the antenna on the wing of a drone
- Heterogeneous Integration
 - Combining multiple components into one package
 - Multilayer chips
- Real time repair
 - Printing new interconnects or circuit traces
- Environmentally Sustainable
 - Use only the materials you need with minimal chemical processing

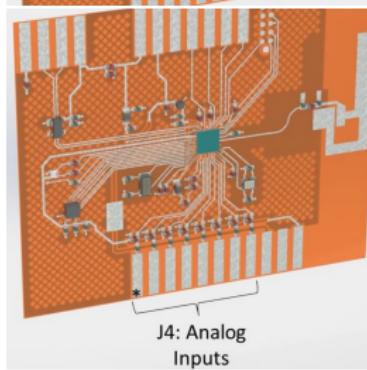
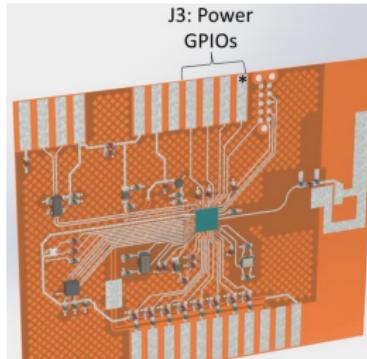
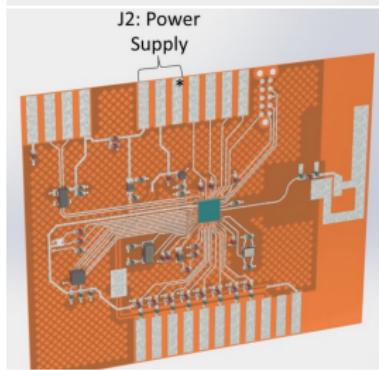
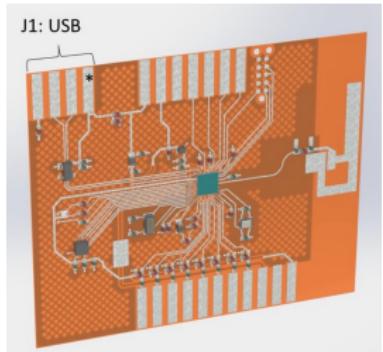


Flexible Hybrid Electronics (NextFlex A21)



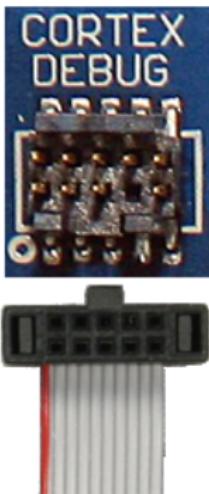


NextFlex A21 GPIO Pins)





ARM Cortex 10 pin JTAG Connector

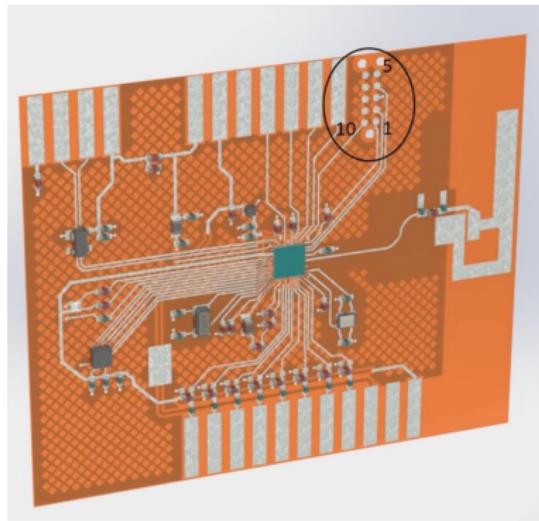


Cortex Debug
10-pin Connector

VRef	1	<input type="checkbox"/>	<input type="checkbox"/>	2 SWDIO / TMS
GND	3	<input type="checkbox"/>	<input type="checkbox"/>	4 SWDCLK / TCK
GND	5	<input type="checkbox"/>	<input type="checkbox"/>	6 SWO/EXTa/TRACECTL / TDO
KEY	7	<input type="checkbox"/>	<input type="checkbox"/>	8 NC/EXTb / TDI
GND/Detect	9	<input type="checkbox"/>	<input type="checkbox"/>	10 nRESET

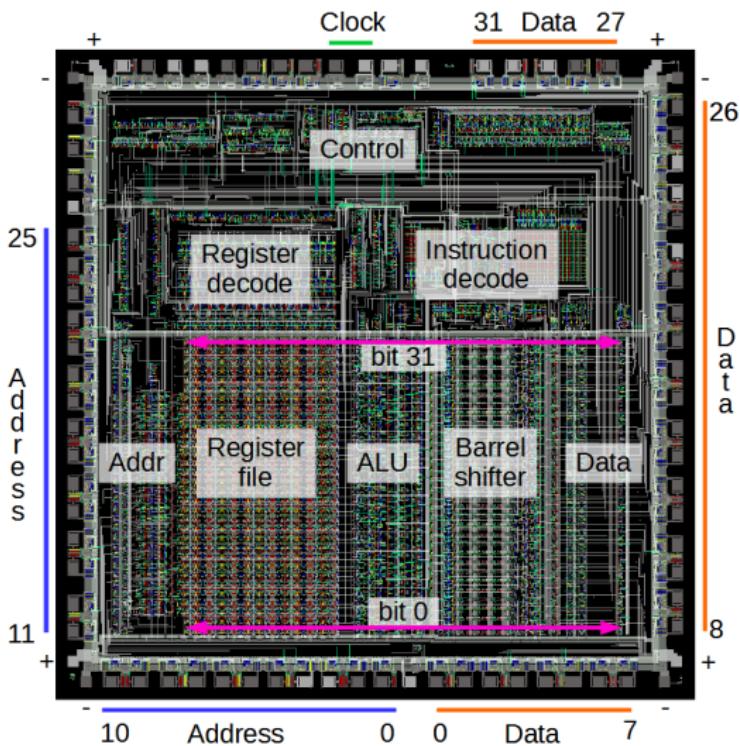


A21 JTAG programming jig



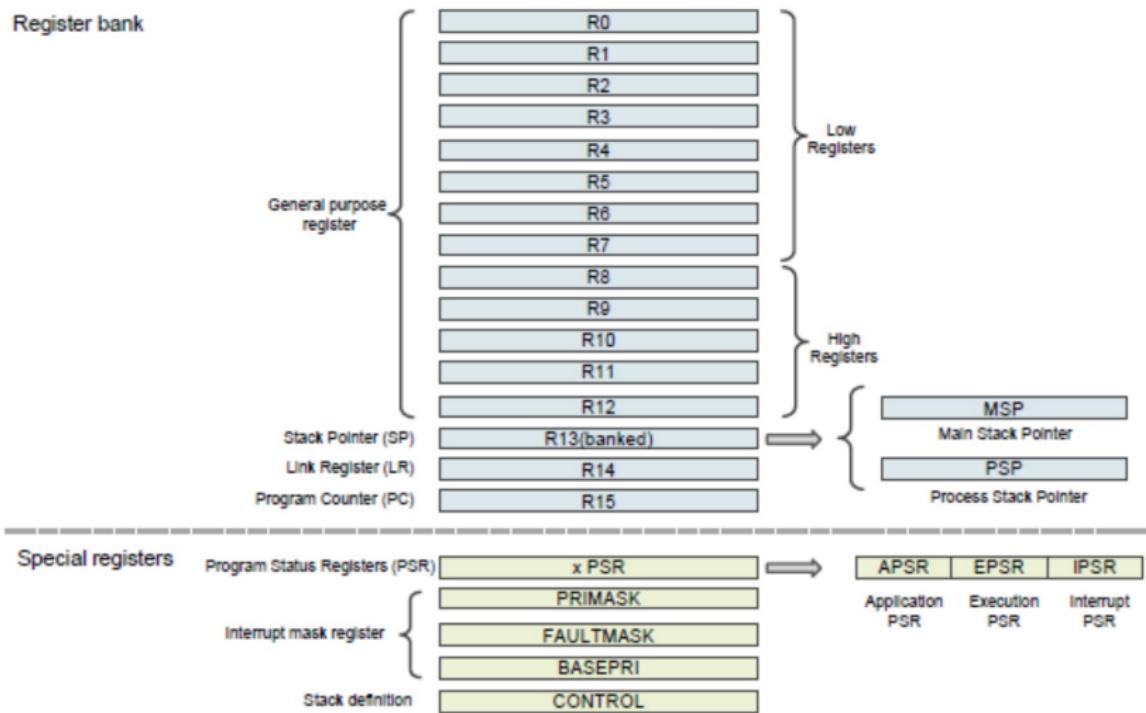


ARM Layout (ARM1 for simplicity) - Registers





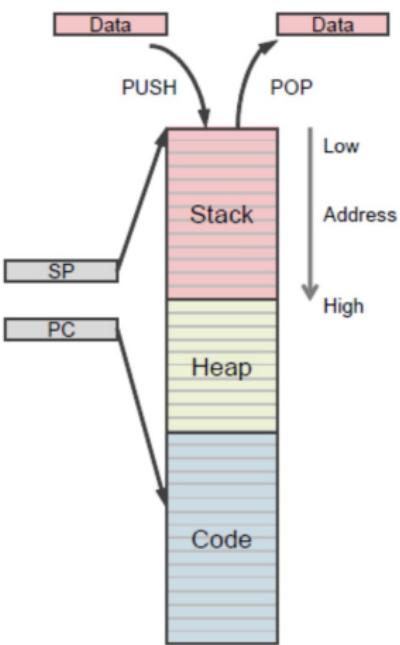
ARM Cortex M4 Registers





ARM Cortex M4 Registers

- R0 – R12: general purpose registers
 - Low registers (R0 – R7) can be accessed by any instruction
 - High registers (R8 – R12) sometimes cannot be accessed e.g. by some Thumb (16-bit) instructions
- R13: Stack Pointer (SP)
 - Records the current address of the stack
 - Used for saving the context of a program while switching between tasks
- Cortex-M4 has two SPs: Main SP, used in applications that require privileged access e.g. OS kernel, and exception handlers, and Process SP, used in base-level application code (when not running an exception handler)





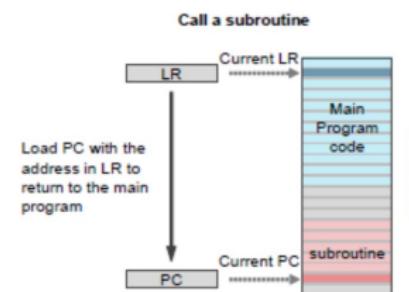
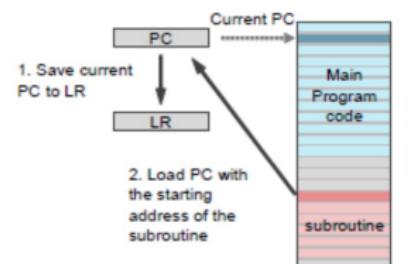
ARM Cortex M4 Registers

- Program Counter (PC)

- Records the address of the current instruction code
- Automatically incremented by 4 at each operation (for 32-bit instruction code), except branching operations
- A branching operation, such as function calls, will change the PC to a specific address, meanwhile it saves the current PC to the Link Register (LR)

- Link Register (LR)

- The LR is used to store the return address of a subroutine or a function call
- The program counter (PC) will load the value from LR after a function is finished





ARM Cortex M4 Registers

- xPSR, combined Program Status Register
 - Provides information about program execution and ALU flags
 - Application PSR (APSR) item Interrupt PSR (IPSR)
 - Execution PSR (EPSR)
- Application PSR (APSR)
 - N: negative flag — set to one if the result from ALU is negative
 - Z: zero flag — set to one if the result from ALU is zero
 - C: carry flag — set to one if an unsigned overflow occurs
 - V: overflow flag — set to one if a signed overflow occurs
 - Q: sticky saturation flag — set to one if saturation has occurred in saturating arithmetic instructions, or overflow has occurred in certain multiply instructions



Installing Segger Embedded Studio

① Install JLink

- <https://www.segger.com/downloads/jlink/>
- Check the Box for Use Legacy USB - if that option is available

② Install Segger Studio

- <https://www.segger.com/products/development-tools/embedded-studio/technology/installation/>

③ Setup License using License Manager

- Get MAC address by using: Tools → License Manager → Diagnose problems
- Request a Free License: <https://license.segger.com/Nordic.cgi>
- Activate: Tools → License Manager → Activate Segger Embedded Studio



Assignment: NextFlex A21



- ① Open the A21_IoT_Firmware project using File → Open Solution
- ② GENTLY place A21 into programming jig, connect to your computer.
- ③ Target → Connect J-Link.
- ④ Build → Clean Solution
- ⑤ Build → Build Solution
- ⑥ Target → Download A21_Demo

Follow along with the instructor to learn how to use Debug mode



Assignment: NextFlex A21: Modify main.c



- ① Create functions to light up the LEDs cyan, magenta, and yellow
- ② Modify the variable datatypes from `uint8_t` to `int16_t`
- ③ Increment count by 256 instead of by 1
- ④ Add printing `someNumber` and `sum` to the "count" print statement
- ⑤ Create a `random(min,max)` function
 - Using `rand()` within the function, allow for a min and max to be set.
 - Modify `main(): someNumber = random(0x00BA,0x7000);`

Capstone



Capstone Projects

Intent:

- Based on a direct observation or need expressed by a guest speakers.
- Original work demonstrating the skills obtained in this class.
- Demonstrate the ability to work as part of a team.
- A pitch to potential employers or investors.

Guidelines:

- Create a Particle (Photon 2 or Argon) based product.
 - ESP32-CAM may be used as secondary controller if camera needed
- Code MUST follow the IoT Style Guide
- Needs to include a Cloud Dashboard component and concepts from Module 15 - In the Wild
- Project will include a video, presentation, GitHub, and Hackster.io.

Previous capstone projects can be found at: <https://www.youtube.com/playlist?list=PL0t2Pk5ETDgxfVptdyr6xbL6MW1-5CJey>